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FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Feasibility of a Plant at Anaconda Montana

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2.0 INTRODUCTION

In considering wood waste as a feedstock for ethanol production, it must be realized that the chemical makeup unique to raw wood dictates plant processing requirements within fairly narrow limits. The so-called lignocellulosic character of natural wood is actually a systematic mosaic of carbohydrate compounds interlaced with lignin and held together in rigid structures by strong chemical bonding forces. Reasonably rigorous reaction conditions, therefore, are required to disrupt the stable chemical structure and release the carbohydrate fractions for conversion to ethanol and other marketable products.

The Madison Wood Sugar Process was developed to convert the cellulose and hemicellulose components of raw wood to simple sugars, utilizing mineral acid hydrolysis of wood waste under controlled conditions. The resulting hydrolysate contains six-carbon sugars (hexoses) derived from cellulose and five-carbon sugars (pentoses) from hemicelluloses.

The Madison process served as the basic model for the preliminary plant design presented herein. Modern conventional fermentation and distillation systems were incorporated to convert six-carbon sugars to anhydrous ethanol and to convert five-carbon sugars to furfural and animal feed-grade molasses.

A detailed analysis was performed on wood waste resources available for an Anaconda, Montana plant site, complete with determination of economic operating radius for feedstock gathering and delivery.

All economic findings from the study were pooled and subjected to cash flow analysis to measure business prospects for the potential plant installation.

3.0 PLANT PARAMETERS AND PROCESS DEVELOPMENT HISTORY

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3.0 PLANT PARAMETERS AND PROCESS DEVELOPMENT HISTORY

3.1 PLANT SIZING AND SITING

Funding for this investigation was obtained by a grant from the Montana Department of Natural Resources and Conservation (1). The work statement section of the grant contract specified the plant size as 2,500,000 gallons per year and the plant siting at Anaconda, Montana. Therefore, these fixed parameters were used as guides in the development of the preliminary plant design, in the survey of wood waste resources, and in economic analysis of the potential business venture.

3.2 PROCESS SELECTION

The fuel ethanol system to be used in this project was specified to utilize the Madison wood sugar process,[1] including modifications to incorporate more recently developed technologies where advisable. In developing the preliminary plant design, certain modifications were made to the basic Madison process. A major adaptation consisted of the inclusion of steam explosion equipment for autohydrolysis of wood waste prior to its entry into the digestion vessels of the Madison system. Another important change was made by replacement of the original lime slaking system with more modern, easily automated equipment for tighter control of acid hydrolysate neutraliztion. These changes are described in Section 7.0.

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(1) Department of Natural Resources and Conservation Grant Number 451-811.

3.3 EVOLUTION OF WOOD SUGAR PROCESS DEVELOPMENT

The Madison wood sugar process evolved from experimental and commercial developments in acid hydrolysis of wood that spanned more than one and one-half centuries. The first recorded work was that of Braconnot[2] who discovered in 1819 that cellulose dissolved in concentrated mineral acid solutions was converted to sugar. Following that discovery, research was carried out sporadically in Europe and the United States in attempts to develop economically sound processes for making sugar products from wood.

Ethyl alcohol production from wood hydrolysates was practiced commercially in the United States as early as the World War I era, with the so-called "American Process".[3] This process utilized a hydrolysis procedure based upon dilute sulfuric acid. Hydrolysis was carried out in a rotary digester, with short reaction time and comparatively low temperatures. Under these conditions, the process liberated sugars only from the most easily hydrolyzable material in the wood feedstock. Resulting sugar yields were of the order of about 22 percent of theoretical maximum.

Two commercial plants were constructed and operated on the "American Process" during World War I years. One plant was located at Georgetown, South Carolina and the other at Fullerton, Louisiana. Both plants contained fermentation systems with ethanol as their end product. These plants produced over 5,000 proof gallons of ethanol per day and operated in competition with fermentation plants producing ethanol from molasses feedstocks. In time, shortages of wood material and low molasses prices forced both plants to close.

Wood hydrolysis by acid treatment was the focal point of substantial process research attention in the time period between World Wars I and II. Among the processes developed during the period, one in particular emerged as the most readily economical and became known as the Scholler process.[4,5,6,7] This process, connected to ethanol fermentation systems, achieved particular prominence in Germany during World War II when it was used in plants producing ethanol fuel for the German war effort.

The Scholler process was distinguished by sugar yields reported to range from 70 percent to 77 percent of theoretical maximum. It employed dilute sulfuric acid and steam pressures up to 200 psi in a stationary digester. Unlike the "American Process" which preceded it, the Scholler method introduced recycle-leaching circulation of digestion liquors whereby many batches of acid liquor were passed through the same wood charge. Digestion times of 16 to 20 hours were required to complete the wood hydrolysis step.

American rights to the Scholler process were acquired by the Cliffs-Dow Chemical Company in 1935.[2] This company conducted pilot plant testing of the process in their facilities at Marquette, Michigan, with encouraging results. In 1943, the War Production Board requested that a program of process development be expedited to yield a plant design for ethanol production from wood. The Forest Products Laboratory of the U. S. Department of Agriculture was designated to conduct the program, and initial pilot plant testing took place in the Cliffs-Dow facilities. From these tests and other work, the Madison wood sugar process[1] was developed.

A full-scale wood hydrolysis and fermentation plant was designed using the Madison wood sugar process. The plant was built at Springfield, Oregon, with a design capacity rating of about 5,000,000 gallons of 190° proof ethanol per year.

Construction on the Springfield, Oregon plant was completed after the end of World War II.[2] By the time of its completion, the urgency of its mission had passed and ample supplies of low priced petroleum were becoming available for ethanol production by the inexpensive ethylene route. Although the plant had been operated in experimental runs, additional capital was judged to be needed to bring it into full operation in continuous running. Under the economic conditions that prevailed at the time, general interest and government sponsorship soon waned and the plant was closed.

3.4 DEVELOPMENT OF THE MADISON WOOD SUGAR PROCESS

With the embodiments of the Scholler process (References 4-6, 8-18) accepted as representing the most advanced state-of-the-art in wood hydrolysis to sugars, systematic experimentation began in 1943 to re-evaluate the process and to seek improvements. Work performed by the Forest Products Laboratory (References 1, 2, 19-21) showed that a number of steps in wood hydrolysis procedures described by Scholler (References 7, 22-31) offered opportunities for improvements in sugar yields, energy efficiency, and functional life of some plant components. For example, it was shown that reduced sugar yields and inordinate usage requirements for acid and base were the result of the Scholler batch digestion process, with its intrinsic hydrolysis periods ranging from 16 to 20 hours. Moreover, steaming and holding periods for the wood charge between acid batches were shown to promote sugar decomposition and to call for elaborate manipulation of valve controls.

The Madison wood sugar process was developed to eliminate or minimize the outstanding deficiencies of the Scholler process, from which it was principally derived. Extensive pilot plant work was conducted on Douglas fir wood waste, and Tables 3-1, 3-2, 3-3, and 3-4 summarize the experimental findings. Figure 3-1 presents a process schematic diagram of the wood sugar section of the pilot plant developed to perfect the Madison wood sugar process.

Under pilot plant conditions, using mixtures of mill edgings, chipped slabs, sawdust, and shavings, an improved hydrolysis process was perfected. It employed sulfuric acid solutions of 0.5 to 0.6 percent strength at temperatures of 150° to 180°C, with the dilute acid flowing continuously through the charge of wood. A markedly shortened hydrolysis time was accomplished, because of more rapid removal of sugars from the digester. Sugar decomposition was reduced due to shorter residence times in acid solutions, with consequent improvements in alcohol yields.

The Madison and Scholler processes were directly compared for alcohol production in pilot plant equipment.[1] The sugar yield derived from one ton of dry, bark-free Douglas fir wood waste for each process was fermented to ethanol. Using the Madison process, 2.8 hours hydrolysis time resulted in 64.5 gallons of 190°F proof ethanol, as compared to 13 to 20 hours and 55 gallons for the Scholler process.

Taken together, the lines of process development work leading to the Madison wood sugar process streamlined and automated the majority of steps in conversion of wood to sugar components and systematized production and recovery of chemical byproducts. The highlights of the process advancements were as follows:

a. A steaming-packing system for loading wood waste into the digesters for subsequent hydrolysis;

b. A top-loading method of acid delivery to the digesters, automatically controlled, to facilitate rapid hydrolysis from percolation of acid solutions through the wood charge;

c. Automatically controlled removal of sugar solutions from the bottom of the digesters, to minimize acid-catalyzed destruction of sugar components;

d. Controlled flashing of sugar solution liquors immediately downstream from the digesters, to set temperature and pressure conditions for furfural and methanol recovery; and

e. Stepwise stabilization of steam usage and steam recovery to maximize energy efficiency of the overall plant system.

Interest in wood-to-ethanol processing laid dormant during the period between World War II and the 1970's, when the 1973-1974 Arab oil embargo immediately focused global attention upon alternate energy resources and processes for their utilization. Motor fuel alternatives to gasoline began to receive high priority, and ethanol from biomass quickly became a focal point for process research and economic analysis in the United States and in other nations as well. The basic Madison Wood Sugar Process was generally accepted as the bench mark for process improvement in research on ethanol production from cellulosic feedstocks, including wood waste.

Physical treatments of wood waste to increase ethanol yields have centered largely upon autohydrolysis techniques through steam explosion, while yield improvements in hydrolysis of cellulosic materials to free sugars have been sought primarily through enzyme treatments.

Reviews of steam explosion processing methods for wood waste have been presented by Lora and Wayman[32] and by Taylor.[33] Wayman, _et_. _al_[34] presented experimental findings where autohydrolysis treatments were followed by either acid or enzyme digestion. These workers reported sugar yields from aspen wood exceeding 80% of theory from acid hydrolysis procedures similar to the Madison process on autohydrolyzed wood. Enzymatic digestion carried on in parallel experiments produced sugar yields up to 99.9% of theory, but five-day incubation was required with 10% enzyme concentration on the wood substrate.

Excellent reviews of progress on enzyme saccharification of cellulosic materials have been published by Garden, _et_. _al_ [35] and Spano, _et_. _al_.[36] Emert and Katzen [37] have published extensive findings combining different grinding methods on cellulose feedstocks with subsequent chemical and enzyme hydrolysis procedures. Innovative processing concepts have been presented by the Swiss team of Mendelsohn and Wettstein,[38] who adapted the basic principles of the Madison process into a semicontinuous acid hydrolysis system connected to continuous fermentation.

As part of the recent interest in manufacture of fuel-grade ethanol from biomass feedstocks, subjects of extensive analysis have been capital cost requirements and overall production economics. Best known reports of the findings include those of Wayman, et. al,[34] the Mitre Corporation,[39] Hokansen and Katzen,[40] and Robertson, Nickerson.[41]

An overview of experimental work as described above leads to the conclusion that enzyme hydrolysis developments have not yet reached the stage of economic feasibility for wood waste processing. They may approach economic validation in more highly purified cellulose sources such as newsprint. Autohydrolysis through steam explosion has been a reasonably well documented process in technical efficiency and can be justified as an economic improvement as an addition to the basic Madison Wood Sugar Process.

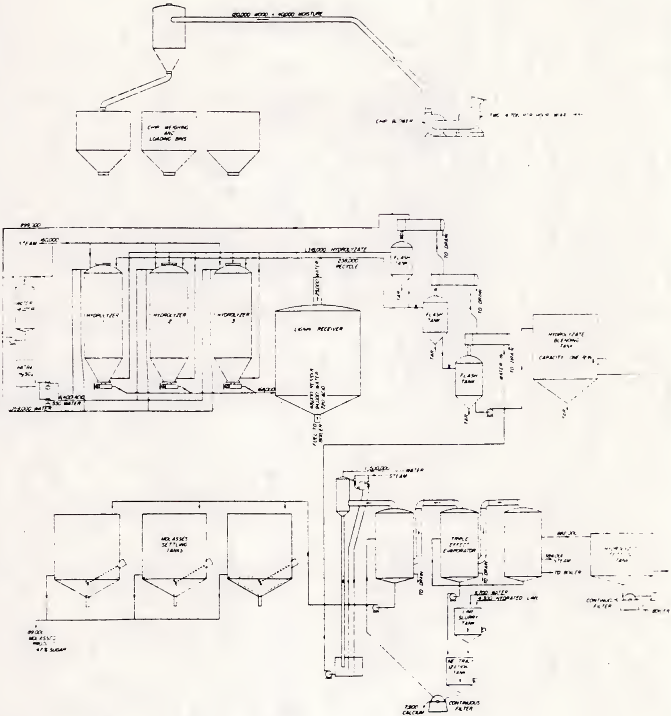

FIGURE 3-1.--A wood-sugar molasses plant processing 60 tons of dry wood per 24 hours. All quantities in pounds per 24 hours.

From Reference 2, Section 3.5.

TABLE 3-1.--Composition and products from Douglas-fir sawmill waste.

Form of wood	Composition		Yield of hydrolysis products					
			At 0.5 percent or less concentration of reducing sugar			At 5.0 percent concentration of reducing sugar[1]		
	Potential reducing sugar content	Potential fermentable sugar	Total reducing sugar	Fermentable reducing sugar	Alcohol	Total reducing sugar	Fermentable reducing sugar	Alcohol
	Percent	Percent	Percent	Percent	Gallons per ton	Percent	Percent	Gallons per ton
Bark	37.5	26.4	18.4	11.2	16.9	15.3	9.3	13.9
Sawdust (13.5 percent bark)	63.2	53.4	44.6	37.1	55.5	41.6	34.6	51.9
Slabs, bark-free	67.5	57.0	48.9	40.6	61.0	39.0	32.1	48.5
Slabs, mill-run (35 percent bark)	56.3	47.4	38.7	31.0	45.0	30.4	24.4	36.6
Hog fuel G, select removed (52 percent bark)	50.9	42.1	35.3	28.3	42.5	29.2	23.4	35.1
Shavings[2]	67.6	57.1	...	...	...	...	...	...

[1] Except in case of bark, where hydrolysis was discontinued when concentration of reducing sugar being removed is 1 percent or less.

[2] Pilot-plant hydrolysis not made because of inability to charge sufficient amounts in the digester.

From Reference 1, Section 3.5

TABLE 3-2.--Hydrolysis of Douglas-fir sawmill wood waste using batch addition of dilute acid and discontinuing the hydrolysis when the total hydrolyzate averages approximately 5.0 percent.

Run No.	Kind of wood waste	Dry wood	Bark-free wood	Hydrolysis time	Sulfuric acid[1]	Reducing sugar solution	Solution concentration	Yield[1] Reducing sugar	Yield[1] Alcohol
		Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gallons per ton
176	Hog waste..................	455	296	3.4	6.6	2,800	5.00	47.3	59.1
178	Do.......................	500	324	3.3	6.9	3,200	4.75	47.0	58.8
179	Sawdust..................	430	370	3.0	6.3	3,250	4.97	43.8	54.9
194	Do.......................	420	364	2.9	6.1	3,305	4.90	44.6	55.6
220	Do.......................	350	302	2.9	7.6	2,950	4.82	47.0	58.7
221	Do.......................	370	320	3.0	6.9	3,060	5.10	49.0	61.0
187	Hog waste,[2] 35 percent; Shavings, 65 percent......	354	300	3.0	7.0	3,250	4.53	45.2	56.5
188	Hog waste,[2] 54 percent; Shavings, 46 percent......	450	366	3.2	6.5	3,550	4.80	46.7	58.3
217	............(3)............	400	337	3.0	7.3	3,200	4.72	45.0	57.5
218	............(3)............	409	340	3.0	6.6	3,200	4.73	44.5	55.6
232	Slab-wood chips and sawdust................	399	332	3.1	6.6	3,130	5.10	48.0	60.0

[1] Values based on bark-free wood.

[2] Hogged sawmill waste containing 50.9 percent bark.

[3] Hogged wood waste containing 40 percent shavings and 20 percent sawdust.

From Reference 1, Section 3.5.

TABLE 3-3.--Continuous hydrolysis of a charge of Douglas-fir wood waste, using continuous addition of the dilute acid and continuous removal of the sugar solution.

Run No.	Wood waste		Bark-free wood[1]	Time	Acid[1]	Solution	Reducing sugar concentration[1]	Reducing sugar yield	Alcohol[1]
	Hog fuel	Shavings							
	Lb.	Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gal./ton
263	282	108	294	2.6	6.5	2,400	4.95	40.5	50.5
264	292	102	294	2.5	6.3	2,400	4.67	38.2	47.6
265	300	123	321	2.5	7.5	2,700	4.56	38.3	47.9
266	320	151	362	3.0	5.5	2,800	4.55	36.5	45.7
267	282	170	364	2.7	5.0	2,850	5.10	40.3	50.3
269	310	148	367	3.0	6.5	3,250	4.87	43.7	54.6
273	255	144	315	2.5	5.7	2,600	5.08	41.9	52.4
274	231	141	293	2.7	7.4	2,700	5.20	40.6	50.9
275	235	146	301	2.7	5.2	2,530	5.30	44.6	55.7
276	246	151	316	2.7	6.3	2,830	5.03	45.0	56.2
278	230	142	294	2.7	6.3	2,800	4.83	46.0	57.5
284	235	143	296	2.8	5.9	2,800	4.36	41.1	51.5
285	280	147	329	3.0	4.6	2,800	4.77	40.5	50.6
286	253	109	293	2.5	5.1	2,440	4.88	40.6	50.8
287	290	131	319	3.0	5.7	2,800	4.96	43.6	54.5
288	282	120	303	2.7	5.8	2,400	5.00	39.7	49.6
289	294	104	295	2.7	5.8	2,400	4.30	35.0	43.8
292	500	....	325	2.8	5.5	2,800	5.00	42.9	54.6
293	278	151	331	3.0	6.5	2,800	5.04	42.6	53.3
294	273	165	344	3.0	6.0	2,800	5.00	40.7	51.0
295	298	137	330	2.8	5.7	2,800	4.86	41.2	51.6
296	290	140	329	3.0	6.2	2,800	4.75	40.5	50.6

[1] Values calculated on the basis of bark-free wood.

From Reference 1, Section 3.5.

TABLE 3-4.--Hydrolysis of Douglas-fir sawmill wood waste, using batch addition of first charge, followed by continuous introduction of acid and continuous removal of sugar solution.

Run No.	Hog fuel B (35 percent bark)	Shavings	Dry wood	Bark-free wood	Hydrolysis time	Acid	Reducing sugar weight	Reducing sugar concentration	Yield, bark-free wood	Alcohol concentration	Yield
	Percent	Percent	Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gm. per 100 ml.	Gal. per ton
247	100	....	451	294	3.0	5.8	3,020	5.05	52.0	1.96	65.0
245	100	....	465	302	3.0	6.2	3,000	5.08	50.3	1.97	63.0
248	75	25	448	328	3.1	5.3	3,100	5.18	43.8	2.03	61.0
249	75	25	470	340	3.0	4.5	2,900	5.25	45.0	2.04	56.0
250	72	28	478	344	2.7	4.9	2,700	5.65	45.6	2.20	57.0
252	50	50	460	370	3.0	5.0	2,950	5.15	41.5	2.01	52.0
253	50	50	436	357	2.8	5.4	3,100	4.90	42.5	1.90	53.0
254	52	48	434	350	2.9	5.6	3,100	5.40	48.0	2.12	60.0
255	54	46	447	364	3.1	5.6	3,200	5.48	48.2	2.14	60.2
256	54	46	447	364	3.1	5.6	3,300	5.18	47.0	2.01	58.9
257	100	....	444	290	2.9	7.0	3,200	4.85	53.3	1.89	65.6
262	70	30	385	293	2.8	6.7	3,000	5.01	51.5	1.95	64.3
268	62	38	457	358	3.2	6.3	3,640	4.96	50.5	1.94	63.2
270	56	44	380	314	2.6	5.9	3,100	4.95	49.0	1.93	61.3
271	59	41	353	313	2.7	6.5	3,000	5.06	48.5	1.97	60.7
277	65	35	380	296	2.7	6.7	3,100	4.92	51.5	1.92	64.3
279	70	30	417	319	2.8	7.0	3,500	5.00	54.8	1.95	65.5
280	65	35	412	322	2.9	7.0	3,500	5.00	54.5	1.95	68.0
281	64	36	405	318	2.8	6.5	3,500	4.80	52.7	1.87	66.0
282	67	33	392	302	2.8	6.8	3,200	4.85	51.4	1.89	64.2
283	67	33	386	299	2.5	6.2	3,200	5.10	54.5	1.99	68.2
290	67	33	415	319	2.8	6.8	3,200	5.00	50.2	1.95	62.7
291	72	28	450	339	2.5	5.5	3,200	5.30	50.2	2.06	62.7
297	68	32	405	308	2.7	7.0	3,120	5.04	50.8	1.96	63.5
298	49	51	387	303	2.9	7.2	3,300	5.10	55.5	1.99	69.0
299	67	33	449	343	2.7	6.4	3,650	4.80	50.8	1.87	63.5
302	70	30	391	285	2.6	7.3	3,200	4.85	54.5	1.89	68.2
303	71	29	407	305	2.8	6.8	3,315	4.90	53.1	1.91	66.5
304	70	30	401	301	2.6	6.8	3,100	5.10	52.5	1.98	65.5

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4.0 SURVEY OF WOOD WASTE RESOURCES

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4.0 SURVEY OF WOOD WASTE RESOURCES

ABSTRACT

The finalized wood ethanol study described in the attached report included as one of its objectives a systematic attempt to quantify wood residues for feedstock and document both present and future availability of such residues within a prescribed radius encompassing the Anaconda, Montana site.

The ethanol plant featured in the study was a 2.5 million gallons per year facility using the modified Madison fuel grade ethanol (FGE) process, and was estimated to consume approximately 289 ± 4 green tons per day; this green-ton feedstock requirement is the equivalent of approximately 168 ± 2 oven-dry tons. For purposes of this study, feedstock was defined as including logging residues (e.g., slash), mill wastes (e.g., fine and coarse sawdust), and recycled cellulose fiber (e.g., newsprint).

Documentation of availability of wood residue was based primarily upon literature review and contacts with forest specialists to produce descriptions of Douglas fir and lodgepole pine forests.

The U.S. Forest Service timber appraisal method and R. Withycombe's model were applied to the representative forest conditions. In both cases, a 1981 price ceiling of $40 per green ton was assumed; thus, the findings remained economically competitive with other potential users of forest and mill residues.

The economically-acceptable hauling distances considered and established in the study ranged all the way from zero to 19.5 miles, depending upon the specific combination of model, harvest, and haulage conditions; however, the degree of uncertainty underlying these findings was sufficient to justify an extension of the study bounds to encompass an enlarged circle with a 25-mile radius extending from the Anaconda site.

Past, present, and projected timber harvest acreage figures were combined with the above residue yield figures to provide estimates on residue production within the 25-mile radius, over the 20 years of presumed ethanol plant operation. The total logging residue estimate based on assumptions as to model, transportation, etc., ranges from 42,450 to 64,728 green tons per year over the facility's lifetime. However, competition between the various commercial and residential users for these residues will be sufficiently great that as little as 65% of annual production may be available for FGE consumption; this level of competition could shrink the supply of residue to a range of 27,592 to 42,073 green tons per year, due to existing competition.

The inventory of available mill residue not committed to other uses (e.g., particle board construction) appears optimistically to range from 17,170 to 25,754 green tons per year depending on assumptions. These figures assume a continuance of at least 1976 levels of pulp/paper production throughout the plant's service life; yet mill waste production is presumed to expand up to 1.5 times the 1976 levels by the year 2010. The expected contributions from recycled cellulose fiber range from 9,100 to 20,130 green tons per year. These figures reflect the uncertainties in cost-effective collection and centralized processing of large volumes of this resource, plus seasonal variability in its supply and potential market competition for other uses (e.g., insulation).

Based on study results, the feedstock requirements appear to be 3.6 times the levels originally envisioned. Investigation revealed that feedstock costs would range from \$1.68 per green ton for recycled cellulose fiber transported within three miles of the plant site to \$92.20 per green ton for harvesting, on-site handling, and transporting of logging residues. This latter cost is due largely to the low volume per piece characteristics of the residue. Thus, assuming a \$40 ton ceiling to compete with other potential users, more residue is available than if the FGE facility can afford to pay only \$25 ton (in 1980 dollars).

The substitution of costs developed during the study into the harvest-transport cost estimate models discussed herein shrinks the radius of economic feasibility to a fraction (0.625; i.e., from 40 to 25 miles) of the originally presumed radius. Furthermore, the apparent competition with the private sector and the residential use of the residues is probably greater than assumed earlier. The large pulp and particle board industries located in Missoula, Montana already are making nearly complete use of the mill residues present within and adjacent to the designated study area.

Finally, the wood-ethanol study did not support the earlier belief that the 2.5 million gallons per year facility was feasible. The apparent discrepancy between the initial inventory and the subsequent wood-ethanol study has as its most likely explanation the different manner of estimating the size of the economically available resource base.

4.1 INTRODUCTION AND BACKGROUND

The wood ethanol study described herein was performed primarily to fully investigate a premise initially offered in a grant proposal submitted to the Department of Natural Resources and Conservation (DNRC) under the Alternative Renewable Energy Sources Program in 1980.[1] The initial premise included an assumption that enough wood waste (i.e., forest and mill residue) existed within an approximate 40-mile radius of Anaconda, Montana to provide feedstock for the 2.5 million gallons per year fuel grade ethanol (FGE) facility. However, early in this initial investigation and prior to developing detailed economic and engineering feasibility analyses, the researchers realized the need for additional site-specific studies regarding wood waste availability.

4.1.1 Objectives

Primary objectives of the wood waste resource study were to: 1) define the various types of residue sources that could serve as feedstock for motor fuel grade ethanol (FGE) with use of a modified Madison process[2]; 2) document these residues as to respective quantities and qualities, location, and physical availability for economical delivery to the Anaconda plant site; and 3) project over the 20-year life span of the FGE facility their respective contributions to maintaining production.

Preliminary economic analyses were conducted to establish area boundaries for the feasibility studies. The wood waste resources study was designed to be compatible with subsequent economic feasibility studies; this was necessary because competition with other potential users could have restricted availability of waste wood for FGE feedstock over the life of the project.

4.1.2 Definition of Wood Resources

The two principal sources of wood fiber feedstock for ethanol production are those residues related to timber harvesting and milling.[3,4] Municipal dumps, landfills, and community recycling centers may provide wood fiber as feedstock for the ethanol plant.[5,6] These resource categories are defined in the following paragraphs.

Forest residues of value for feedstock include those resulting from forest growth and management activities plus logging residues resulting from timber harvesting. The forest residues include natural mortality losses (e.g., due to insect infestation, fires, severe storms); unmarketable trees culled from within commercial forest stands (i.e., land capable of growing at least 20 ft^3/acre or producing at least 0.3 tons of biomass/acre/year); and noncommercial or surplus timber stands composed largely of overmature, standing dead or diseased "junk" timber in need of environmental thinning to optimize the stand's timber productivity potential.

Logging residues include the pole-size trunks over eight feet in length and three inches in diameter which can be utilized in a current logging operation; however, this material may not be harvested in a cost-effective manner. All of the remaining above-ground wood fiber on the site subsequent to timber harvest is also classified as logging residue.[7] The latter category includes branches and foliage, rejected portions of the cut trunks, and understory vegetation, which is collectively termed "slash."

The manufacturing of lumber, plywood, and wood pulp generate various kinds of mill residues including the following:

- Coarse, chippable, residues such as wood slabs, edges and trimmings;
- Cores from plywood plants which in Montana usually are cut into lumber;[7]
- Fine residues composed of sawmill planer shavings and sawdust, plus sawdust from veneer mill and panel trimmings from the layup mill;
- Bark from lumber and plywood manufacturing; and
- Pulping/paper mills which generate considerable quantities of bark from the debarking of green pulping stock.

Considerable amounts of wood and wood fiber products are discarded daily in municipal solid waste. Paper is a major component (by weight and by volume) of domestic and commercial refuse, and possesses a great salvage potential. Presently, newsprint is selectively collected, graded, and baled at the Butte and Anaconda recycling centers. Once de-inked via mechanical and/or chemical treatment(s), the processed paper fiber could serve as a supplemental feedstock for ethanol production. If economical, the paper feedstock may be expanded to include a mixture of old fiber containers and non-waxed boxboard, old wrapping paper, paper bags, plus discarded books and magazines. Convenient sources for such wastes include office buildings, large retail outlets, warehouses, and transportation terminals. Wood waste produced by local construction and demolition/salvage activities, that has been separated from its tramp-metal, is an additional source of potential wood fiber.

Cooperation and coordination of groups generating such wastes could result in a relatively homogeneous, minimally contaminated (e.g., by waxes, dyes, metal) source of secondary fiber. Properly managed, the relatively low flow rate of such materials may supplement reliably that acquired from forest and mill activities.

4.2 METHODOLOGY OF INVENTORY STUDY

4.2.1 Methodological Overview

The essential objective of the wood residue inventory study was to determine the adequacy of the wood residue resource base in the vicinity of Anaconda to support both ongoing and planned uses, including its potential for FGE production. Thus, intensity of competition for the resource base and its renewability potential were important concerns.

The study, conducted in three-phases included: quantification; assessment of competition; and assessment of renewability.[4] Initially, the total existing resource base was quantified to the extent possible. Competition for this base was examined under the two categories of: 1) alternative resource utilization (e.g., timber salvage for wood chipping/paper production), and 2) alternative land uses (e.g., areas where the timber is reserved or harvest is deferred until some future date). Finally, the ability of the study area to maintain (or even increase) production of the resource base was addressed.

An estimate of average annual residue availability for FGE production can be determined through application of the following resource availability expression, as modified from Tillman[4]:

$$R_E = \Sigma\,[(R_P + R_S) - R_U] - R_M$$

The term R_E represents those residues which are available (apparently) for FGE production. The term R_p represents residues generated by the primary forest industry, including those produced by forest growth and mortality, forest management practices, forest harvest practices, and forest products manufacturing processes. R_S represents residues generated by secondary wood and wood fiber recovery and recycling activities. R_U represents residue that appears to be uneconomic to harvest and utilize. R_M represents residues designated for other purposes, including pulp and paper production, particle and composition board production, in-plant steam/electricity generation, residential heating, etc.

Given a physically available feedstock supply within a defined study area, more detailed economic feasibility analyses can be performed. Such results would indicate the relative cost-competitiveness of residue use for FGE production versus other potential end uses.

It must be recognized that specific point or confidence interval estimates of resource quantity are difficult to generate. Such a conclusion is based on the following facts:

- R_p reflects regional economic variables (e.g., fluctuating demand for raw timber and finished wood products) plus site-specific forest growth rates and changing growth/silvicultural management variables;
- R_S reflects market incentives for widespread collection, concentration, and delivery to the ethanol facility;

- R_U is subject to varying environmental constraints (e.g., steep terrain having highly erodible soils), ease of access and harvest/yarding/ haulage costs; and
- R_M is correlated with those regional economic variables that influence also Rp, plus market incentives for substitution of wood for more conventional fossil fuels for energy production and space heating.

Thus, ultimate physical availability of the resource base will vary over time, being a function of the selected geographic area and assumptions made regarding the various terms in the above expression. The ultimate economic availability will occur when no higher market value than that represented by the FGE facility is available for the subject residues.

The resource availability expression presented above guided all information gathering activities. Necessary data were acquired through literature review and personal telephone interviews plus correspondence with regional forest specialists. Details of methodology are discussed below.

4.2.2 Establishment of Information Needs

4.2.2.1 Estimation of FGE Feedstock Requirements

The FGE facility would be designed to operate 330 days per year, 24 hours per day, and would produce about 2.5 million gallons of fuel grade ethanol per year; this activity will extend over a 20-year operating period. A mixture of Douglas fir bark and wood, when treated under presumed commercial-type operating conditions, may yield one gallon of anhydrous ethanol for every 41 to 42 dry pounds of feedstock.[8] However, it must be noted that such feedstock requirements have been extrapolated from optimal pilot plant conditions. For example, the pilot plant feedstock requirements varied from 32 to 35 dry lb/gallon at the Forest Products Laboratory[8] to 31 to 41 lb/gallon as cited in Hokanson _et al_.[2] In addition, the pilot plant value is considerably higher than the 27.4 lb/gallon projected for the proposed wood-ethanol facility to be sited in Thompson Falls, Montana.[9]

The major commercial forest types present within a 50-mile radius of Anaconda, Montana are proportionately (by acreage) by descending order of occurrence: lodgepole pine; Douglas fir; and ponderosa pine.[10] However, to simplify matters, the species harvest ratio (on a species by acre basis) was assumed to be 0.45:0.45:0.05 respectively for lodgepole pine, Douglas fir, and "other" (e.g., ponderosa pine, western larch,). It was assumed further that the biomass would be allowed to dry somewhat during the 30-day storage period prior to use. Consequently, the weight-percent moisture contents were taken to be 36 and 50 for Douglas fir bark and wood, respectively; 55 for lodgepole pine wood; and 60 for the "other" species.[3] The weighted average for all subject species was thus computed to be 47.1 percent (w/w) moisture content. Thus, a range of 0 to 12 percent moisture in an oven dry ton would translate to 1.89 to 1.54 "green" tons of biomass. Table 4-1 shows the range of feedstock requirements that are applicable if various combinations of assumptions hold true. It was decided that feedstock requirements were best represented by the average of the two "moderate" cases, i.e., approximately 289 ± 4 green tons per day. This figure is equivalent to yields of about 44 dry lb/gallon FGE or about 76 green lb/gallon FGE. Fuel needed for process steam generation (and possibly steam/electric cogeneration) must be addressed in addition to the above FGE feedstock requirements. Depending upon resource availability and economic considerations, additional wood residues or subbituminous coal could serve these additional energy requirements.

4.2.2.2 Demarcation of Supply Area: Preliminary Economic Analysis

It was assumed initially that areas harvested for residues would vary most often from even-aged lodgepole pine stands to uneven-aged Douglas fir (or mixed conifer species) stands. It was also assumed that the species-specific characteristics discussed below are representative of medium to over-stocked commercial forest lands.[11]

For lodgepole pine the following assumptions are applicable:

- About 75 percent of the total acreage occupied by this species (within a 50-mile radius of Anaconda) ranges from 3 to 5 in. diameter at breast height (dbh), while the remainder averages 8 to 9 in. dbh;
- The number of stems per acre varies from 450 to 800 in "doghair" stands (i.e., dbh <4 in.) to 220 to 250 on commercial stands (e.g., suitable for post/pole and saw timber harvest);
- Production of merchantable biomass varies from 7500 to 9500 board feet (bdft) per acre or 2100 to 2400 cubic ft. (cf) per acre on commercial forest lands; and
- A harvest volume defect of 3 to 5 percent exists in merchantable trees.[12]

For Douglas fir it was assumed that:

- The trees average 9 to 10 in. dbh;
- The number of stems varies from 100 to 150 per acre in situations varying from mixed lodgepole pine/Douglas fir stands to second growth Douglas fir stands;
- Production of merchantable biomass ranges from 6000 to 7000 bdft per acre or 1600 to 1900 cf per acre on commercial forest lands; and
- A harvested volume defect of 6 to 8 percent exists.[12]

In regard to commercial timber harvest practices, it was assumed that:

- Percent slope ranges from approximately 0 to 40, but averages nearer to 15 to 20;
- Ground skidding utilizes most often medium-weight tracked or rubber-tired vehicles;
- Yarding distances vary from 500 to nearly 1500 ft, but average closer to 800 to 900 ft; and
- Forest-wide, multi-species scaling defects ranging from 6 to 10 percent, but averaging 8 percent.[12]

Following from the first assumption (on slope), two additional assumptions were made:

- As mechanical fallers are generally not cost-effective at slopes greater than 15 percent, hand falling of timber will be practiced; and
- As flat landings of about 75 x 150 ft dimensions are probably uncommon within the potential harvest area, the chipping of residues will occur most likely at the FGE plant site.[13]

Table 4-2 presents the assumed volume of wood by component in mature stands of lodgepole pine and "dry site" Douglas fir forests.[14] Large volumes of timber were harvested for domestic and industrial purposes in the Butte-Anaconda area between the late 1870's and about 1918.[10] Assuming an 80- to 120-year rotation period,[12] not all of the area's commercial timber lands can be construed to be necessarily "mature" or "old growth" stands. Furthermore, over the next twenty years, timber harvests will most likely shift to greater proportions of young-growth stands with less residue volume per acre. Assuming a 50:50 ratio between new growth and selectively cut old growth (virgin) stands in western Montana, the estimated logging residue volume may be, "35 to 45 percent lower than an estimate based solely on a harvest composed entirely of old growth."[15]

Table 4-3 presents the average piece number and volume per piece estimates for commercial lodgepole pine and Douglas fir cover types. Standing dead submerchantable timber (i.e., $\leq$ 3 in. dbh, 7 to 10 ft lengths) could increase the tabulated estimates by 100 to 150 per acre and 25 to 30 per acre for lodgepole pine and dry Douglas fir sites, respectively (as extrapolated from Reference 14, Table 4).

Table 4-4 presents the average number of sound pieces of down wood and average volume (cf) estimates per forest type. Table 4-5 presents estimates of "other logging residues" (Section 1.2), including down woody materials ranging from 0.25 to three-inches dbh, plus duff. Forest floor duff is composed of a mixture of unincorporated organic materials (e.g., conifer needles, deciduous leaves, twigs); its depth is measured between the bottom of the looselycast litter layer (01 horizon) down to the surface of mineral soil. Inspection of the data for woody material loading per acre for a given forest cover type reveals the expected and considerable variation in biomass. Such variation is influenced by the habitat type(s) and yield capability of the areas sampled, plus stand fire and timber harvest histories. As tree mortality and downfall occurs at all stand ages, no substantive relationship between downed biomass loadings and stand age is observed.[16] The depth and quantity of duff varies somewhat between forest cover types, while intra-type variability is influenced mostly by the aspect (north or south) where sampling occurred.[16]

Table 4-6 indicates that 4,842 and 2,562 cf per acre of feasibly harvestable biomass exist for the lodgepole pine and Douglas fir cover types, respectively. These quantities assume clearcutting practices to close utilization standards. Close utilization of the woody biomass will gather at least the amount of material per acre that would be available if the area was cut according to conventional utilization practices.[17] The lower bound would occur in commercial thinning units composed of a young, mixed-conifer stand, where biomass production would be approximately 20 percent (on a cf per acre basis) of that expected if it were clear cut to conventional utilization standards (Reference 17, pp. 5, 11). For purposes of this study, clearcutting to close utilization standards was chosen as it optimizes harvest efficiency and cost-effectiveness; the matter of cost-effectiveness is discussed below.

The above harvestable biomass values assume that a sufficient amount per acre of woody residues will be left upon the site to accomplish the following:

- Not interfere adversely with ectomycorrhizal/nutrient cycling activity (Reference 16, p. 9);
- Not disrupt future timber productivity;[18] and
- Minimize adverse environmental damage (e.g., sedimentation, soil profile disruptions) overall.[19]

The retrieval of cull materials, tops, submerchantable trees, and a portion of the standing dead trees and down trees using conventional harvest practices is most cost-effective when done concurrently with saw timber logging operations. Additional wood fiber may also be gathered at this time (e.g., slash from old logging sites and dead material on sites not immediately scheduled for logging). However, under economic constraints, the "cost of this additional material could not be any less than logging residue and its value per unit (i.e., per cubic foot) would not be any greater," (Reference 20, p. 6). Generally these other sources either have higher costs or lower usage potential than logging residues or have ready markets (such as posts); thus, their inclusion in the potential feedstock resource would not improve the profit potential (Reference 20, p. 11). It becomes apparent that costs will be minimized and biomass harvest rates and volumes maximized by conducting wood resource gathering in conjunction with commerical timber sales and harvesting operations.

These conservative viewpoints could be modified favorably if federal and state subsidies, such as the following, were in effect:

- Increasing the level of hard money appropriations for (timber access) road construction, then prorating such investments over the various timber sales subsequently occurring in the given area;

- Offering energy credits on taxes paid by lumber or mineral development companies for upgrading the quality of the road system(s) under their control; this may open up areas of otherwise unsuitable or marginal timber; and
- Increasing the incentives for the yarding of unmerchantable materials, if possible.

The economic and political climate required to implement these incentives is uncertain; thus, such advantages cannot be depended upon to cause significant increase in the wood fiber resource base. Again, the reliance on clearly profitable instances of timber harvest is the safest policy, particularly as the study area's national forest system comes under increasingly more regulated management.[21]

The timber and residue handling assumptions utilized in the study cost estimations were as follows:

- For lodgepole pine, timber is cut into 16 ft sections and has an average net (merchantable) volume of 3.8 cf (Table 4-3);
- Utilizable logging residues range from eight to 30 ft (16.8 ft average) in length and possess an average gross volume of 3.85 cf (Table 4-4 and Reference 11, Table 2);
- For Douglas fir, timber is cut into 16 ft sections and has a merchantable, average, volume of 5.1 cf (Table 4-3);
- Utilizable residues average 19.4 ft in length and possess an average gross volume of 6.1 cf, (Table 4-4, Reference 15, Table 2);

- On-highway log trucks having a maximum haulage capacity of 1040 cf and load limit of 52,000 lb are utilized to haul the timber/wood fiber; while,
- Capacity is reduced to 30,000 lb for pieces smaller than 10 cf due to "the difficulty of loading many small pieces on a truck" (Reference 13, p. A-6).

In order to evaluate potential road quality between any given timber harvest area and the FGE facility site, pertinent 1:250,000-scale AMS quandrangle sheets[22] were compared against county-wide land use maps which depicted commercial forest lands; these latter maps were prepared by the Montana Department of Community Affairs.[23] From this inspection, it was concluded that the following road grade ratio was not unreasonable:

- Highways with excellent alignment and a slope range of ± 6 percent, 0.33;
- Double-lane roads having a mixture of paved and graveled surfaces and a slope range of ± 8 percent, 0.25;
- Single-lane graveled road with ditch, fair to poor alignment and a slope range of ± 8 percent, 0.30; and
- Single-lane dirt road without ditch, fair alignment and a slope range of ± 8 percent, 0.12.

4.2.2.3 Estimating Radius of Economic Feasibility

The first example for estimating the radius of economic feasibility utilized the USDA Northern Rocky Mountain Zone average timber appraisal costs, as adjusted for the presumed variability in harvest site conditions.[24] The results indicate a felling/limbing cost of $40.84 per thousand board feet (MBF), regardless of tree species harvested. Furthermore, the skidding cost was calculated to be $44.99 per MBF. The mechanics of these calculations are summarized in Table 4-7. As discussed above, the costs of processing logging residues would be at least as expensive as those incurred for saw timber operations. The two above estimates probably represent the upper bound of credibility for saw timber, and may be applicable to logging residues. The zone average-derived appraisal costs (for saw timber and poles) tend to be greater than costs actually observed within the study area.[12] Data pertaining to cost estimations for loading/unloading and transportation of saw timber are given in Table 4-8; this information was combined with data from the previous table to estimate an overall radius of economic feasiblity. Table 4-9 presents in detail the means of deriving an estimated one-way haulage distance (radius) of 4.4 miles.

The above haulage radius of 4.4 miles appeared to be surprisingly low; thus the calculation of economic radius was repeated. For this second example, the following modifications were added:

- Felling/limbing and skidding costs were reduced 25 percent (an arbitrary, optimistic estimate following from conversations with USFS personnel).[12]
- Loading/unloading times were reduced 15 percent (probably optimistic, as residues are more difficult to handle than saw timber due to the former's greater heterogeneiety in form and volume characteristics);
- The average haul tonnage of residues was increased 182 percent to 27.5 green tons per load;[25]

- The paved:unpaved road ratio was optimistically increased to 0.75:0.25, thus reducing the cost per mile factor to about $0.72 per mile; and
- The road quality was upgraded to allow a 150 percent increase in average speed to 17.2 mph (also extrapolated from past conversations with USFS personnel).[12]

These changes implemented in the second example increased the previously calculated radius of 4.4 miles to 19.5 miles, as shown in Table 4-10. The averaging of the two extreme estimates results in a "moderate" value of 12.0 miles. For simplicity's sake, it was concluded that all errors made in the above assumptions are sufficiently compensating that this 12.0-miles radius is a credible estimate when using the Forest Manual as a cost-estimate model.

The R. Withycombe cost appraisal model was utilized in the second example for estimating the radius of economic feasibility.[13] Information necessary for the use of this model is summarized in Table 4-11. The calculated radius for the various possible cost and resource use scenarios are summarized in Table 4-12. Inspection of the results indicates that only Douglas fir can be utilized economically, but only when the saw timber/wood fiber sources are situated within a few miles radius of the FGE site. If the estimates of the second example above are in error by 50 percent (Ref. 13), the upper bounds of feasiblilty would approach 6 miles radius. This conclusion assumes break-even economics for both logger and plant operator (i.e., no profit-taking), plus no external subsidizing of incurred costs. Overall, the radius of economic feasibility determination is very sensitive to assumptions pertaining to timber and wood fiber harvesting, transport, and in-plant processing costs. Apparently, the economical range varies from zero to 19.5 miles (radius) and tends towards a moderate figure of about 7 miles. Therefore, it was concluded that a 25-miles radius should encompass the utilizable resource base. However, site-specific harvest conditions, market conditions, etc., could reduce this boundary radius to less than one-half of this estimate.

The major topographic and cultural features present within the 25-mile radius plant operating area are shown in Figure 4-1.

4.3 RESULTS

4.3.1 Primary Forest Industry

4.3.1.1 Commercial Forest Lands Inventory

The Deer Lodge National Forest contains approximately 687,649 acres of non-reserved commercial forest lands (CFL) within the standard, special and marginal series of the timberland use scheme presently utilized.[26,27] The Beaverhead National Forest's Wise River and Wisdom Ranger Districts contain similarly 107,443 and 206,323 acres, respectively.[28,29] An estimated 11,295 acres of regulated lands belonging to the Helena Ranger District of the Helena National Forest are located either within or adjacent to the general study area.[30] The study area also straddles the U.S. Department of Interior, Bureau of Land Management's Dillon, and Missoula Sustained Yield (timber management) Units. These units contain about 171,733 and 100,000 acres of commercial forest lands, respectively.[31,32]

About 2,800 acres of "miscellaneous federal" commercial forest lands are present within Beaverhead County.[33] Such lands are administered by agencies other than the Bureau of Land Management, National Forest Service, and USDI Bureau of Indian Affairs. The proportionate ownership of non-federal commercial forest lands present within the designated five county study area is given in Table 4-13. Inspection of BLM surface ownership maps indicates the following predominance pattern of commercial forest land ownership in order of decreasing magnitude: Deer Lodge National Forest; Beaverhead National Forest; private non-industrial; Bureau of Land Management; Montana State Lands; and private industrial (e.g., Burlington Northern) lands.34

It must be recognized that the estimated 2,071,293 acres of commercial forest lands (CFL) available in central and western Montana for supplying the FGE's feedstock requirements is an optimistic figure. This average may be somewhat less when the following constraints are considered:

- The geographic area represented in the above estimate is about 6.5 times the size of those lands where wood residue recovery appears to be economically feasible (Section 4.2.2.3; Reference 10, p. 12);
- Maintenance of timber harvest at 1980 levels through this decade on USDA Northern Region Forest Service lands will require at least a three-fold increase in direct Federal access investments (Reference 35, p. 47); furthermore, the acreage figure for the Deer Lodge National Forest may shrink to as low as 520,000 acres--if a low-to-moderate level of investment is allocated for timber management;[36]
- Montana state agency ownership patterns vary from one county to another; subsequently, the rate of timber harvest will also vary in response to various combinations of natural resource management objectives--it cannot be assumed that all 99,000 acres of Montana State lands will be available for harvest over the next 20 or so years;
- A high probability exists that only a "modest portion" of the private non-industrial lands will be available for timber harvest, relative to that arising potentially from private industrial or publically owned lands;[37] and
- Only 10 to 15 percent of the Deer Lodge National Forest's commercial forest lands (CFLs) will be accessed every 10 years, as required under current multiple-use, sustained yield timber management policies.[38]

Therefore, it is evident that a 6.5-fold reduction in the CFL base would result in 318,660 acres being available to supply the FGE facility's wood fiber requirements. This downward revision in CFL areal extent probably represents a realistic upper bound to the resource base. The rationale for this assessment is given below. Inspection of the Montana Department of Community Affairs' (DCA) (1977) land use maps for Deer Lodge, Granite, Powell, and Silver Bow Counties indicates a CFL estimate of 174,720 acres. Correlation of the DCA land use maps with the BLM surface ownership maps plus the Deer Lodge National Forest (1976) planning unit map indicates that an additional 26,266 acres of CFL probably exist within Beaverhead and Jefferson Counties' areal contribution to the study area. Inspection of the Deer Lodge National Forest planning map indicates that approximately 353,280 acres of USFS lands exist within the study area. However, if Forest averages for total forest cover and commercial forest lands are utilized (i.e., 76.3 percent and 74.7 percent, respectively), then the CFL estimate shrinks to 201,370 acres.

Inspection of a Bureau of Land Management document indicates a CFL resource base of about 3,400 acres in the vicinity of Wise River, Montana.[39] A maximum of 5,098.5 acres of BLM lands exist within the Flint Creek drainage of the Philipsburg Planning Unit.[40] However, only about 1,600 acres of this unit are present within the study area; thus, the Philipsburg Planning Unit figure could be halved to make a more reasonable estimate of its contribution of CFL acreage.

A correlation of DCA land use and BLM surface ownership maps concluded that: 1) Montana State contribution to the CFL base appears to be about 39,853 acres, while 2) private industrial forest acreage is approximately 2,620 acres.

Finally, although county land ownership maps were not correlated to the DCA land use maps, the comparison of land use maps against BLM surface ownership maps indicates that non-industrial private CFL tracts total considerably less than 71,200 acres (derived by dividing 462,300 by 6.5). An estimate below the 71,200 acre figure was used because much of the private non-industrial lands are situated in the lower-slope foothills where moisture availability limits both tree growth and response to thinning; however, this is not to say that timber stand improvement via precommercial or commercial thinning will be unsuccessful. Although these lands contain large amounts of small diameter roundwood (for posts, poles, and pulp), development opportunities are marginal due to access problems, market distances, and high freight rates.[41] Also it appears that the balance between acres-cut-over and areas being restocked to timber, "is being rapidly upset" in Granite County[42] where much of the "private land has been logged to the extent that it will be several decades before another crop can be harvested. Some of the timberland has been logged with the intent to convert it to grazing land," (Reference 43, p. 138). In summary, the above resource analysis suggests a realistic estimate of CFL availability (within the 25-mile radius of the Anaconda study area) to range from an upper bound of 318,660 acres to a lower bound of 200,986 acres.

The recent trend of timber resource utilization was investigated via acquisition of harvest data from local federal and state forestry offices. The results, expressed in terms of thousands of board feet (MBF) are shown in Table 4-14. A derivative tabulation of estimated acreage utilized and estimated percentage of the total acreage available is presented in Table 4-15. The data in this latter table imply that approximately 13,977 acres per year of commercial forest lands are at least committed to timber harvest. This estimate is equivalent to an annual access rate of 0.85 percent of the CFL resource base. Factors that could modify the immediate usefulness of these values include:

- The influence of short-term market demand on rate of harvest--acres of timber sold is not necessarily equal to acres of timber cut;
- Actual timber volume varies from 2000 to over 10,000 bd ft per acre, depending upon stand (species) composition and site quality; plus
- It was assumed that conventional clear-cutting occurred on each hypothetical 7500 bd. ft per acre tract.

Thus, prior to calculating a logging residue per year estimate for the 25-mile radius study area, two concerns were addressed: 1) the representativeness of the above trend (i.e., timber resource utilization), as viewed from broader historic and future timber harvest perspectives; and 2) the influence of species composition on applied silvicultural/timber harvest practices.

A literature review indicates that a general decline in annual roundwood harvest occurred over the period 1969 to 1976. The low point was reached in about 1975 when the proportionate harvest was about 50:50, public versus private lands (see Reference 48, Figure 2, p. 13,). Throughout this period, the relative contribution from federal lands has been decreasing more or less annually; these circumstances have probably been influenced by CFLs deferred from harvest for either NEPA- or RARE I/II-related reasons.[49] At the same time, the roundwood contributions from private lands have been increasing proportionately. This national forest land vs. private land shift in harvest contributions appears to be evident within the general study area, as shown in Table 4-16. Inspection of the data implies that a cross-over in relative contributions may have occurred as early at 1973. However, the data presented in Table 4-17 indicates that regional U.S. Forest Service contributions to the overall timber harvest base may increase considerably--relative to the 1975 to 1976 figures, respectively. If the rates of timber harvest on other public lands and non-industrial private lands are maintained at present levels, while harvesting on private industrial lands declines by up to 40 percent over the next 25 to 30 years (see Figure III-13, p. 45, Reference 35), then by the year 2010 the overall rate of timber harvest may still increase 1.25 to 1.50 times over the 1975 to 1976 values. Thus, the estimated rate of annual access to CFLs within the presumed maximum resource supply area varies from 13,977 acres (Table 4-15) to 1.5 times this value; that is, 20,966 acres by the year 2010.

The values discussed assume clearcutting that yields an average of 7,500 bd. ft of merchantable timber per acre; thus the estimates must be adjusted for forest (species) composition and stand characteristics (e.g., age) plus subsequent timber harvest practices. The relative proportion of Douglas fir habitat types, lodgepole pine community types, and subalpine fir habitat types for non-reserved CFLs on the Deer Lodge National Forest is shown in

Table 4-18. The respective ratio of 0.432:0.551:0.017 indicates that lodgepole pine actually is more abundant (on an areal basis) than indicated by the 0.45:0.45:0.05 ratio gleaned from the Headwaters RC and D document.[10]

For purposes of the study in regards to choosing appropriate timber harvest methods, the following assumptions were made:

- Timber management will tend toward creating and maintaining an even-aged stand structure; control of competing vegetation will be included in all cutting plans;
- Subsequently "high elevation" subalpine fir habitat types will undergo shelter wood cutting; "low elevation" Douglas fir sites will also be shelter wood cut on slopes greater than 30 percent when occurring on south and west aspects, while clearcutting or seed tree cutting will occur on slopes less than 30 percent; Douglas fir/grass (warm) sites on south and west aspects plus Douglas fir/subalpine fir/grass (cool) sites will be shelter wood cut; 50 percent of all lodgepole pine sites are suitable for clearcutting, while the remainder will be precommercially or commercially thinned;
- Clearcut size (initial openings) will range from 0 to 40 acres for approximately 75 percent of all cases, and will be less than 80 acres in about 90 percent of the cuts; however, shelter wood or clear cutting in response to natural events such as gale-force winds, fire, disease, etc., may often exceed 80 acres in size;
- The dispersal of clear cuts will be varied geographically, thus, mimicking the natural pattern of major forest disturbances (e.g., insect/disease infestations, windthrow and fire); and

- The recommended changes in management intensity and utilization standards for live saw timber stands will be applied--thus reducing slash volume, standing and down residues, plus harvesting small stems if they can be converted efficiently into a useable product.[53]

Using Pfister _et al._[52] plus Brown and See[16] for guidance, the habitat type and community type groupings (from Table 4-18) were arranged in terms of the above timber harvest categories. Assuming that the proportions of these categories are applicable throughout the 25-mile radius area surrounding Anaconda (regardless of land ownership), and that CFL slopes are generally less than 30 percent, then acreages subject to shelter wood/partial cuttings vs. clearcutting can be estimated. The above information and calculated results are presented in Table 4-19. Table 4-6 indicated that approximately 2,592 and 812 cubic feet per acre of forest residues exists for mature stands of lodgepole pine and Douglas fir cover types, respectively. These values are equivalent to 33.0 and 12.2 green tons per acre, respectively (Table 4-4).

Inspection of Figures 10 and 11 in Brown and See (Reference 16, p. 14) indicates that subalpine fir type residue levels vary from 18 to 20 tons per acre in western Montana. The data in Table 4-19 was utilized to estimate the production of logging residues within the 25-mile radius study area. As shown in Table 4-20, the estimate varies from 42,450 to 64,728 green tons per year over the lifetime of the FGE facility. These values represent approximately 44.5 to 67.8 percent of the calculated annual FGE feedstock requirements (Section 4.2.2.1).

4.3.1.2 Mill Residue Inventory

The two objectives of this facet of the study were: 1) to estimate the quantities of coarse and fine mill residues (plus bark) produced per year by the pertinent sawmill, plus post and pole operations; then 2) estimate the portion of this residue that is apparently available for use by the FGE facility.

A statewide directory of forest product industries was utilized to identify and interview a number of regional sawmill operators plus post and pole processors[55]. The results are summarized in Table 4-21. It should be noted that several other firms not listed in the table have gone out of business; e.g., H. and R. Lumber Co., Dillon and Lee Page, Jr., Philipsburg. A number of other firms listed in the directory could not be reached despite repeated attempts; it is not unreasonable to presume that some of these operations have ceased since the 1978 publication of the directory. The data in this table appear to verify the two earlier judgements: 1) because most of the 25-mile radius study area is situated along the fringe of the major timber production area (e.g., relative to timber levels of northwestern Montana) the majority of the mills are widely scattered, small volume, one to three person operations that process timber at levels allowed by current market conditions[57]; and 2) Champion International plus Louisiana Pacific probably utilize 90-plus percent of all such residues within a 150- to 200-mile radius of Missoula.[58]

A more comprehensive estimate of area-wide mill waste production is presented in Table 4-22. Prior to estimating mill production within the specific Anaconda study area, it must be recognized that the tabulated data include many mill sources situated some distance outside of the economically feasible haulage radius of 25 miles or less. It is not unreasonable to assume that no more than 20-percent of the Table 4-22 grand totals arise from the designated 25-mile radius study area. The rationale for this statement is derived from inspection of the saw timber origin and movement data presented in Keegan (Ref. 48, Table 26, p. 23). It also represents the resource status prior to expansion of the Packaging Division of Champion International's Frenchtown operations. The expanded pulp mill operations, "will leave the state of Montana with a demand for mill residue that is considerably in excess of the supply generated annually in the state, assuming a 1976 level of production," (Ref. 7, p. 13). Furthermore, it appears unlikely, "that supplies from Idaho and Wyoming could do more than augment residue supplies to existing mills," (Ref. 7, p. 13).

It was assumed optimistically that 1976 levels of uncommitted mill residues represent the minimum tonnage available into the future; it was assumed further that production rates may increase to 1.5-times these levels by the year 2010 (see Section 4.3.1.1). Thus, residue quantities will range from 17,170 green tons per year initially to 25,754 green tons per year (by 2010) within the 25-mile radius study area. These levels presume 50 percent by weight (w/w) moisture content in the green feedstock. These values represent approximately 18.0 and 27.0 percent, respectively, of the estimated annual FGE feedstock requirements.

4.3.2 Municipal Wood Fiber Recovery and Recycling Contributions

4.3.2.1 Combustible Waste Inventory

In 1980, an estimated 47,377 tons per year of processable waste was produced within the 25-mile radius study area.[59] This total of useable waste, "does not include non-processable wastes such as earth and fill material, bulky materials, and construction-demolition debris," (Ref. 60, p. 3). If the percentage-by-weight of these wastes that is combustible is assumed to be equivalent of that weight which is fermentable, then 77 percent of the total waste (36,480 tons) should be acceptable FGE feedstock material (Ref. 60, p. 3). The quantity of wastes could rise to 49,613 tons per year by 1990, assuming that: 1) waste generation rates are (will remain) directly proportional to population growth projections; and 2) that the specific Anaconda study area is representative of the larger twelve-county waste management area (Ref. 59, p. I4).

Estimated delivery costs incurred for haulage of waste from local landfills located throughout the area to the FGE facility will apparently range from $1.68 per ton to $23.60 per ton, as shown in Table 4-23. These cost estimates assume: 1) that solid waste delivery to the landfill is paid for via routine waste collection fees or taxes; 2) that costs for separating the fermentable wastes (from the total bulk) is essentially zero (i.e., a successful public education program is in place that encourages such waste segregation at the various primary collection points); and 3) that handling costs at the FGE site can be set at zero dollars, or at least be minimized by prorating the overall feedstock handling costs.

Although the above assumptions are optimistic, the total estimated costs are still below the $40.00 per green ton ceiling that can be paid for logging residues (see Table 4-9). Thus if total solid waste processing costs can be held below this $40.00 limit (per ton), then these materials should be included as a viable source of FGE feedstock. The three landfills at Butte, Deer Lodge, and Anaconda will accumulate wastes generated from Sheridan, Whitehall, and Wisdom, and the estimated 1981 yield of combustible materials will increase to 38,558 tons per year. Thus, as population increases etc., the quantities could rise to 52,438 tons per year by 1990. Furthermore, if all of these wastes are sent to the FGE facility, they would provide at least 40.4 to 55.0 percent of the annual feedstock requirements.

The above stated estimates are conservative; the percent-by-weight fermentable cellulose content in the paper products is considerably higher than that found in the as-received logging or mill residues. However, the above resource evaluation should not be viewed as sufficient reason to shift the feedstock design of the FGE facility away from logging/mill residues towards municipal solid wastes. A more recent solid waste study indicates that Group III solid wastes (i.e., basically all inert materials and used wastes) are, "usually bulky in nature and cannot be collected and transported with solid waste collection equipment or procedures. Thus, when evaluating certain solid waste collection and handling alternatives for the wastes generated in an area, special precautions and arrangements must be made to dispose of these type materials," (Ref. 61, p. 3.22). The Group III wastes generated in Deer Lodge, Powell, and Granite Counties during 1979 totalled 2,935 tons (Ref. 61, Table III-4); projections to the year 2000 increase this estimate to 3,719 per tons year. If the estimated rates of waste generation given in Ref. 59 are proportionally reduced (to be compatible with the above figures), then the potential contributions to the FGE feedstock base decreases to 6.7 to 9.5 percent of overall FGE requirements.

In assessing the long-term reliability of supply, one must recognize seasonal variability in solid waste generation plus potential competition from other energy-intensive activities. The common pattern observed statewide reveals an April maximum (approximately 18 percent above the annual average) and a January minimum (approximately 30 percent below the annual average), (Ref. 61, p. 3.24). In addition, the economics of utilizing solid waste as an energy source in the Missoula area appears to be competitive with sanitary landfill disposal. The system cost analysis performed by HDR indicates a service area representing the majority of the wastes generated in western Montana; their analysis is applicable to any large energy user located in the Missoula area (Ref. 59, p. II-18). Finally, telephone inquiries to local recycling centers indicated that most of the paper wastes (e.g., computer cards/printouts and newsprint) are committed to an insulation manufacturing firm in Great Falls.[62]

In summary, concerns over cost-effective waste collection and handling methods plus seasonal variability in supply and potential market competition for these wastes dictate that these contributions to FGE feedstock supply not exceed 10 percent of the annual average feedstock requirements.

4.3.2.2 Potential Competition From Wood-Gathering Activities for Residential Fuel Source Use

If fossil fuel-related market costs continue to rise, an increase in the proportional use of alternative sources of energy supply can be expected. The study performed by R. E. Erickson et al. indicates that residential wood use in Helena, Bozeman, Great Falls, and Kalispell is about 33.6, 32.1, 27.0, and 40.2 percent, respectively, for the total residences located in these towns; increases in wood use in private residences over the next two years are expected to be 8.2, 7.6, 11.4, and 10.1 percent, respectively.[63] Using these data as a guide, a "ball park" estimate of wood use in the Anaconda area of 25 to 35 percent (of the total households) does not seem to be excessive. Furthermore, it is possible that within the next several years, wood consumption for primary and auxiliary space heating, cooking, and for aesthetic enjoyment (i.e., in fireplaces) may increase an additional 7 to 11 percent.

The purpose of these estimates for the Butte-Anaconda area is to assess the degree of competition expected between local wood gathering (for residential use) and logging-residue harvesting activities for FGE production. An extrapolation of the above survey data[63] to the Butte-Anaconda area implies that wood consumption over such a winter as 1980/1981 could approach 23,000 tons at 25 percent-by-weight moisture content. If the annual estimates of logging residue production (from Table 4-20) are converted to this moisture content--i.e., about 33,069 to 50,423 tons per year--then about 46 to 70 percent of the residue total may be acquired for private use. Although these estimates may be overstated somewhat, there is little doubt that firewood gathering on Deer Lodge National Forest lands removes a significant quantity of combustible/fermentable materials (Ref. 64). If competition develops, the forest is obligated to offer the materials on a competitive basis; they cannot guarantee continued and exclusive use for any given category of user.

In summary, continued private harvesting of logging residues within the 25-mile radius study area could deplete significantly the potential resource base for the FGE facility. It may be possible to arrange a long-term (e.g., 5-year) agreement with the Montana Department of Forestry for purchase of "x" cords per year at "y" cost per cord, adjusted annually to reflect changes in the consumer price index. However, if commercial demand for residues exceeds supply on national forest or BLM lands, acquisition of these materials would be subject to competitive bidding.[65] Thus, public sentiment towards the harvest of residues for private use versus those for FGE production could influence the size of the resource base available for FGE facility use. After considerable introspection, it was decided that about 55 to 65 percent of the annual residue production could be utilized, if available, by the FGE operations without: 1) adversely affecting the supply for residential use, or 2) adversely affecting the presumed "highest-and-best use" policy for resource utilization.

4.4 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4.4.1 Summary

The resource inventory study for the Anaconda site was divided into four phases. At the onset, the range of wood fiber feedstock requirements necessary for producing 2.5 million gallons per year of fuel grade ethanol (FGE) were estimated. Secondly, biomass characteristics for representative forest cover types in the general area of the study site were developed. These estimates served as input to two types of economic models utilized to demarcate geographical boundaries in which feedstock gathering and transport (to the FGE production site) appeared to be economically feasible. Next the total resource base present within these boundaries was estimated. Finally, that portion of the entire wood residue resource apparently available for long-term use by the facility was determined.

The discussion begins in Section 4.1 with a statement of major objectives and definition of important resource terms (e.g., "logging residues"). A methodological overview responding to the objectives is presented in Section 4.2. The first two important conclusions are presented in subsection 4.2.2. It was estimated that 289 ± 4 green tons per day of primarily wood fiber and bark feedstock will be required to operate at the given level of FGE production. This tonnage is equivalent to FGE feedstock requirements of approximately 44 oven dry lb, or about 76 green lb of residue per gallon of product. It was also estimated that: 1) total harvestable biomass yields of 4,842 and 2,562 cubic feet per acre (cfa) are available from lodgepole pine and "dry site" Douglas fir cover types, respectively; these values assume clear-cutting practices to close utilization standards; and 2) of the above totals, about 2,592 and 812 cfa respectively are available as logging residues.

Following additional characterization of the logging residues (e.g., numbers of pieces per acre; cf volume per piece), the data were used in two harvest-transport cost estimate models. In the first approach, the critical assumption was made that feedstock costs cannot exceed $40.00 per green ton. It was judged that this price was competitive with the anticipated pulpwood/fiber product markets, and possibly with the house log market. Application of the U. S. Forest Service Forest Manual timber appraisal method indicated a one-way haulage distance ("radius") varying from 4.4 to 19.5 miles--depending upon subtle changes in such factors as forest cover type, road conditions, etc. It was concluded that all errors made in the assumptions utilized are sufficiently compensating that a moderate value of 12.0 miles served as a credible estimate, if this particular model was used.

The second approach utilized a model developed by Dr. R. Withycombe of the University of Montana's Bureau of Business and Economic Research. The results are more pessimistic, indicating that only Douglas fir can be utilized economically, and only when the saw timber/wood fiber source is situated within several miles radius of the FGE site. If the above estimate is in error by 100 percent, the upper bounds of feasibility would approach a 6-mile radius.

A combination of the two models' results thus indicates radii varying from zero to 19.5 miles, with a tendency towards an average figure of about 7 miles. However, because no statistical limits of confidence could be attached to these values, and because the maximum limit for truck haulage appears to approach 50 miles,[4] the geographical limits were extended to a 25-mile radius from Anaconda.

Section 4.3 presents the estimated lower and upper bounds for annual production of logging residues (4.3.1.1), mill residues (4.3.1.2), and fermentable municipal solid wastes (4.3.1.3) available within the 25-mile radius study area. Distinctions are made between total resource present (e.g., in tons per year) versus the amount expectedly available for FGE consumption, where pertinent or possible.

4.4.2 Conclusions

During the current wood-ethanol study on the Anaconda site (and surrounding documented forest lands) it became apparent that not enough forest and mill residue would be available to support the ethanol plant at this location. The acceptable radius for hauling the required 289 green tons per day of feedstock was assessed generally as being in the 25-mile, or less radius. Based on study results, it was determined that not enough feedstock wood existed within this prescribed circle of 25-mile, or less, radius. Thus, the Anaconda site has been judged as being unacceptable for an FGE plant in the 2.5 million gallons per year category.

As shown in Table 4-24, the estimated FGE resource base for the given study area ranges from 51,152 to 76,887 green tons per year. Given estimated annual feedstock requirements of about 95,370 green tons per year, these figures are equivalent to about 53.6 to 80.6 percent of annual needs. The above range of estimates is more likely to be overstated than understated. The two principal reasons for this evaluation are: 1) given the depth and breadth of data gathering, estimated forest-wide residue quantities probably are not deficient by more than 35 percent (in terms of green tons per acre), while 2) the 25-mile geographical range may exceed the economically realized boundary by 357 to 128 percent (i.e., 25 ÷ 7 to 25 ÷ 19.5 miles, respectively), if this FGE project were to be implemented.

Therefore, if it is assumed that annual feedstock supply must at least equal feedstock demand to assure successful operation, then FGE production at the given scale at Anaconda does not seem possible.

4.4.3 Recommendations

The conclusions of the study do not support a recommendation to implement a 2.5 million gallon per year FGE production operation at the Anaconda, Montana site. However, the two principal alternatives include: 1) an adjustment of operational scale to be compatible with the apparent resource base, but keeping an Anaconda facility site; or 2) locating the facility elsewhere, and recognizing that scale-of-operations may differ from the present case.

Regarding the first alternative, a 1.25 million gallon FGE per year capacity operation appears to be more nearly in quantitative agreement with the given resource base. However, as product costs (i.e., $ per gallon) are not linearly proportional to production scale, the downscaling of operations may not produce a competitive product (e.g., see Figure 3.4.2-C, p. 93 in Hokanson et al.,[2]). A computerized method of economic sensitivity analysis capable of optimizing product cost-effectiveness, given varying assumptions as to resource characteristics and engineering parameters, is recommended. During this down-scaling study, both manual and computer-based literature searches would be performed to identify likely candidate methods; and then the existing software would be tested and refined or new software packages developed as necessary.

The above resource inventory reveals the considerable quantity of uncommitted waste wood fiber present within southwestern Montana. For example, approximately one billion cubic feet of wood waste fiber probably exists within Beaverhead County.[66] If all of this biomass became available to the FGE facility, it would maintain the proposed operations at Anaconda (or elsewhere in the vicinity) for over 200 years. Furthermore, millions of board-feet of timber affected by mountain pine beetle are being cut presently within the Beaverhead National Forest's Madison Ranger District.[67] Dillon, Montana, serves as a collection point for saw timber and subsequent mill wastes; thus, a modestly scaled FGE operation (e.g., $\leq 10^5$ gallons per year) may be able to compete with other local and regional demands for wood fiber. In a similiar vein, the data gathered during the recently-concluded study also indicates that consideration of a more modestly-sized FGE operation located in either the Philipsburg or Lincoln, Montana areas has sufficient potential to merit further investigation.

In summary, the findings of the study are consistent with the USDA Forest Service's assessment that western Montana probably has a moderate potential for alternative energy generation from biomass sources.[55] However, great care must be exercised in choosing a facility site. It must be recognized that areas with abundant resources have attracted prior users and are probably being exploited to some degree that may inhibit entry of a new activity into the field. Conversely, areas with less abundant resources may have greater proportions available for use, but the attendant costs of processing them may be prohibitive. Thus, the preliminary survey of potential FGE sites should systematically integrate the resource potential and resource demand factors.

This could be implemented by creating an inventory matrix (base map) composed of, for example, 1 square-mile cells within southwestern Montana. Each cell would have an ultimate resolution of 160 acres. Two overlays to this lease map would then be generated. The first would display residue isopleths (e.g., in 10 through 50 tons per acre units) while the second would present residue production resulting from timber management/harvest activities.

The generation of a time series of these composites (e.g., at ten year intervals) would aid in determining where and at what quantities the residues will occur. These results would then be converted to availability estimates by over-laying a third sheet depicting likely zones of major competition from other large wood products users. This process is shown graphically in Figure 4-2. These overlays will readily demarcate cells or specific project sites wherein further resource inventory, economic feasibility, and environmental assessment studies appear worthy of the monetary investment required to perform them.

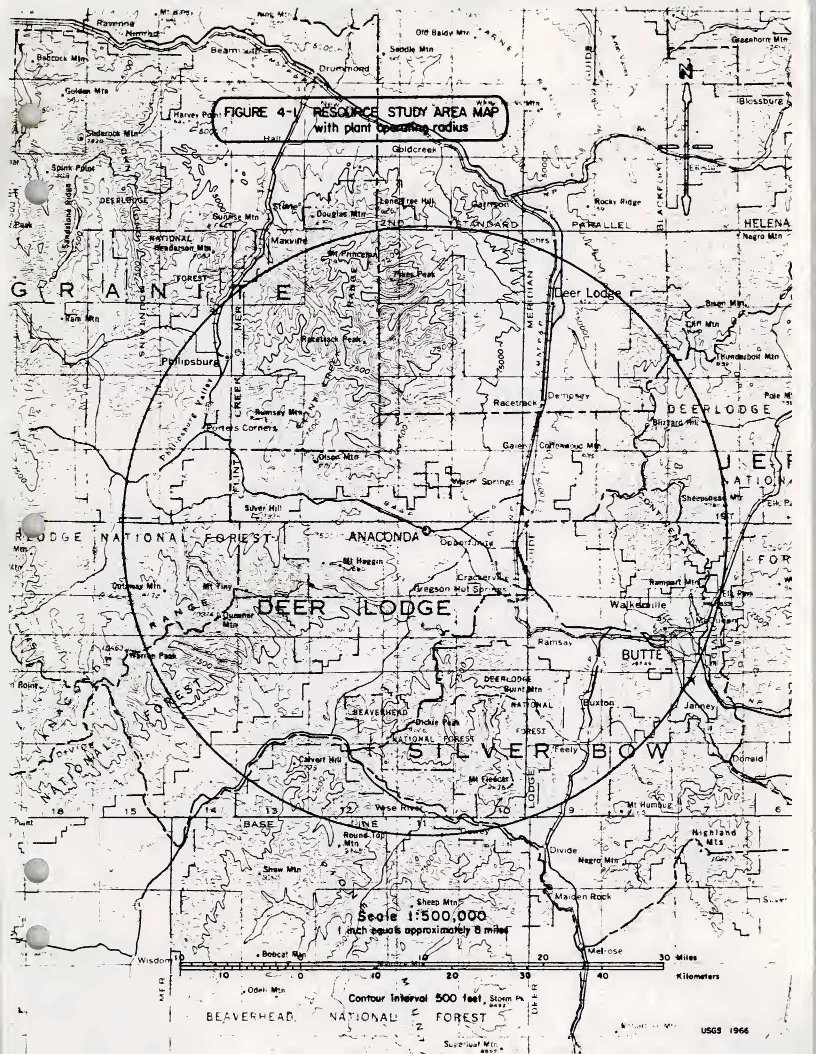
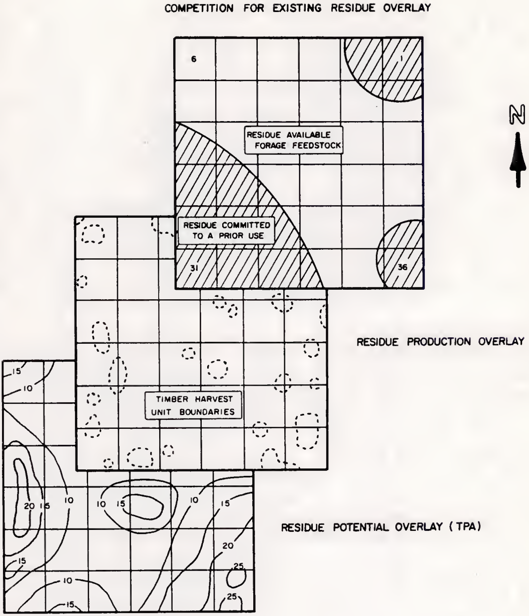


FIGURE 4-1 RESOURCE STUDY AREA MAP with plant operating radius



COMPETITION FOR EXISTING RESIDUE OVERLAY
6
1
RESIDUE AVAILABLE FORAGE FEEDSTOCK
RESIDUE COMMITTED TO A PRIOR USE
31
36
N
RESIDUE PRODUCTION OVERLAY
TIMBER HARVEST UNIT BOUNDARIES
15
10
20
15
10
10
15
10
15
20
25
15
10
15
25
RESIDUE POTENTIAL OVERLAY (TPA)

FIGURE 4-2 GRAPHICAL SUMMARY OF THE PROPOSED SCREENING PROCESS FOR IDENTIFYING POTENTIAL FGE PRODUCTION SITES

Scale: One Square = One Square Mile

TABLE 4-1.--Variability of Feedstock Requirements (In Green Tons Per Day)[a]

		Green Weight ÷ Oven Dry Weight Ratios	
		1.54	1.89
Dry lb. of feedstock required per gallon of FGE produced.	40	233	286
	50	292	358

a) For example, if 1.54 lb of green feedstock @ 47.1 percent (w/w) moisture, can be dried to 1.00 lb @ 12 percent (w/w) moisture, and if 40 lb of dry feedstock are required to produce 1.0 gallon of FGE, then 233 green tons of feedstock per day will be required to meet the annual FGE production of 2.5 million gallons.

TABLE 4-2.--Estimated Volume of Wood by Component in Mature Stands Present Within a 50-Mile Radius of Anaconda, Montana (In Cubic Feet Per Acre).

	FOREST TYPE	
Component	Lodgepole pine	"Dry Site" Douglas fir
Green Trees		
Merchantable logs	2,250	1,750
Cull	120	55
Tops	462	79
Small Stems	247	317
Subtotal	3,079	2,201
Standing Dead		
No defect	441	0
Sound defect[a]	294	82
Solid rot	140	23
Crumbly rot	0	0
Subtotal	875	105
Down		
No defect	360	45
Sound defect[a]	313	20
Solid rot[b]	215	191
Crumbly rot[b]	236	556
Subtotal	1,124	812
GRAND TOTAL	5,078	3,118

Notes:

a) "Sound defect includes crook, sweep, fork, splits, and drying checks that prevent use for solid wood products but not for fiber use", (Ref. 14, p. 3).

b) "Solid rot includes pieces with rot but that can be handled in logging. Crumbly rot is material that will not hold together in logging," (Ref. 14, p. 3).

SOURCE: Adapted from Table 2, page 3 in Benson and Schlieter, 1980 (14).

TABLE 4-3.--Harvestable Piece Number And Volume-Per-Piece Estimates For Commercial Lodgepole Pine and Douglas Fir Forest Types

Tree Species	Average Number of Merchantable Stems per Acre	Average Volume Per Piece (in cubic ft)
Lodgepole pine	470[a]	3.8
Douglas fir	250[b]	5.1

Notes:

a) Assumes an average of 235 trees per acre, each being about 32 feet in height, 8.5 inches dbh, and possessing a gross volume of 9.6 cubic feet. The reduction to a net volume is given by assuming a 4 percent harvested volume defect, a 6 percent scaling defect, and a 10 percent volume (v/v) loss incurred during skidding.

b) Assumes an average of 125 trees per acre, each being about 32 feet in height, 9.5 inches dbh, and possessing 14.0 cubic feet of gross volume. The reduction to a net volume is given by assuming a 7 percent harvested volume defect, a 10 percent scaling defect, and a 10 percent (v/v) loss incurred during skidding.

TABLE 4-4.--Piece Number and (Volume-Per-Piece) Estimates Per Acre for Down Materials in Lodgepole Pine and Douglas Fir Forest Types

	FOREST TYPE	
Length and Diameter[a]	Lodgepole pine[b]	Douglas fir, "Dry Site"[b]
1 to 8 feet long		
3 inches and larger diameter	23 (1.0 cf)	5 (1.4 cf)
9 to 18 feet long		
3 to 6 inches diameter	49 (1.7)	14 (2.0)
6 inches or larger diameter	9 (4.0)	2 (5.5)
19 feet and longer		
3 to 6 inches diameter	28 (3.7)	4 (4.3)
6 inches or larger diameter	18 (8.9)	2 (12.1)

Notes:

a) Assumes mean lengths of 4.5, 13.5 and 30 feet for the three respective length/diameter classes; also assumes maximum diameters of 8.5 and 9.5 inches for lodgepole pine and Douglas fir, respectively.

b) Volumes calculated using Smolian's rule (Ref. 13, Table 10) and assuming density values (at 12% moisture) of 25.5 and 30 lbs per cubic feet for lodgepole pine and Douglas fir, respectively.

SOURCE: Number estimates taken from Table 3, p. 6, in Benson and Schlieter (14).

TABLE 4-5.--Biomass Loading of "Other Logging Residues" For Lodgepole Pine and Douglas Fir Cover Types[a]

	FUEL CATEGORY (TONS $ACRE^{-1}$)		DUFF	
Cover Type	0.25 to 1.0 inch dbh	1.0 to 3.0 inch dbh	Depth in inches	Biomass (tons per acre)
Lodgepole pine	1.2 ± 1.7	3.0 ± 5.1	1.1 ± 0.8	17.4 ± 12.6[b]
Douglas fir	1.6 ± 2.0	2.9 ± 5.4	1.1 ± 0.6	20.4 ± 11.1[b]

Notes:

a) Fuel category and duff depth information acquired by averaging Deer Lodge National Forest and Beaverhead National Forest inventory data, as found in Table 14, p. 43 in Brown and See (16).

b) Assumes duff bulk densities (lbs/ft^3) of 8.7 for lodgepole pine (Ref. 16) and 10.2 for Douglas fir; (Ref. 16 noted a bulk density of 11.2 lbs cubic feet for western hemlock/Douglas fir stands).

TABLE 4-6.--Summary of Number of Pieces and (Equivalent Biomass) Estimates Feasibly Harvested Per Acre For Mature Stands of Lodgepole Pine and Douglas Fir Cover Types, Within a 50-Mile Radius of Anaconda, Montana

	FOREST TYPE	
Component	Lodgepole pine	Douglas fir
Green Trees		
Merchantable Logs	470 (2,250)	250 (1,750)
Cull[a]	25 (120)	8 (55)
Tops	470 (462)	250 (79)
Small Stems[b]	103 (247)	90 (317)
Subtotal	1,068 (3,079)	598 (2,201)
Standing dead[c]	125 (875)	28 (105)
Down trees[d]	104 (888)	22 (256)
GRAND TOTAL	1,297 (4,842)	648 (2,562)

Notes:

a) Assumes dbh characteristics as being the same as that for the merchantable logs.

b) Assumes dbh characteristics are approximaely half that for the merchantable logs.

c) Assumes $\leq$ 3 inch dbh and length averaging 7 to 10 feet.

d) Includes only those pieces at least 8 feet in length and over 2 cubic feet in size; no materials suffering from crumbly rot are added in this total.

TABLE 4-7.--Rationale for Appraisal of Felling/Limbing and Skidding costs vis Use of the USDA Forest Manual

FELLING/LIMBING COSTS[a]

Component	Percent Adjustment Factor
Average dbh = 9 inches	+70.0
Tree density = 125-235 acre^{-1}	- 0.5
Percent slope = 15-20	0.0
Merchantable tree defect = 6%	-12.0
TOTAL ADJUSTMENT	+57.5

Zone average (excluding rent, lease and depreciation) = $22.25
Rent, lease and depreciation = $5.80
Appraisal Cost Estimate: ($22.25 * 1.575) + $5.80 = $40.84MBF^{-1}

SKIDDING COSTS[b]

Component	Percent Adjustment Factor
Net volume acre^{-1} - 7500 MBF	+1.5
Gross no. logs MBF^{-1} = 24	-5.0
Skidding distance = 825 ft.	+2.5
Scaling defect = 8%	-1.0
TOTAL ADJUSTMENT	-2.0

Zone average (excluding rent, lease and depreciation) = $39.18
Rent, lease and depreciation = $6.59
Appraisal cost estimate: ($39.18 * 0.98) + $6.59 = $44.99 MBF^{-1}

Notes:

a) Taken from pp. 2422.41--2 and 2422.41-4 in Ref. 24, FSM 6/81 R-1 Supp 276.

b) Taken from pp. 2422.41--2 and 2422.41--6 in Ref. 24, FSM 6/81 R-1 Supp 276.

TABLE 4-8.--Rationale for Appraising Timber Loading and Haulage Costs vis Use of the USDA Forest Manual

COMPONENT	SPECIES (NO. TREES PER ACRE)	
	Lodgepole pine (36)	Douglas fir (52)
Gross volume (green tons)[a]	15.4	14.8
Loading Time (minutes)[b]	57	$\geq$65
Road Quality--see discussion in text		
Averaged Speed (mph): 11.5[c]		
Transport Costs		
Fixed daily costs = \$64.67[d]		
Labor per day = \$191.03[e]		
Unloading time (minutes)[f]	43	49

Notes:

a) Extrapolated from Table 1, p. 2422.41--20 in the USDA Forest Manual (24); weight per load will presumably meet any road or bridge tonnage limit.

b) Extrapolated from Table 2, p. 2422.41--21 in Ref. 24.

c) Extrapolated from Table 3, p. 2422.41--23 in Ref 24; the weighted average mph was calculated as follows: (15.87 x 0.33) + (10.43 x 0.25) + (8.62 x 0.30) + (8.68 x 0.12) = 11.47.

d) Calculated from p. 2422.41--18 in Ref. 24: \$15,845/245 = \$64.67 operating day^{-1}.

e) Calculated from p. 2422.41--18 in Ref. 24, but using a 10-hr work day: \$229.24 x 10/12 = \$191.03 day^{-1}.

f) Author's observations/impressions gained while serving as an employee for the Flathead National Forest Service, summers of 1971-1976.

TABLE 4-9.--Summary Calculations for Estimating the Economically Feasible Haulage Radius, Using the USDA Forest Manual Model (in 1981 Dollars)

CRITICAL ASSUMPTION: The FGE facility must be able to pay up to \$40.00 green ton^{-1}, thus remaining competitive with the anticipated pulpwood/fiber product markets (and possibly with the house log market--see Ref. 15).

APPROACH:

1. Assume in-plant chipping and associated handling costs of \$3.50 green ton^{-1} (see Table 12, Ref. 13; adjusted to 1981 dollars via use of the projected 1981 annual wholesale price index of 295).

2. Ceiling price per load: 15.1 green tons load^{-1} x \$40 green ton^{-1} = \$604.00 load^{-1}.

3. Conversion of MBF to green tons: \$85.83 MBF x 1 MBF/1000BF x (10lbs/BF)$^{-1}$ x 2000 lbs ton^{-1}, equivalent to \$17.17 green ton^{-1}. The lbs per bd. ft. conversion was taken from Table 11, Ref. 13.

4. Expression for calculating economic feasibility (haulage radius).

   a) $\$604.00 = \$259.27 + (1.783 \text{ hrs.} \times \$19.10 \text{ hr}^{-1}) + \left[\frac{\text{distance (in miles)}}{11.4722 \text{ mph}} \times \$0.882 \text{ mile}^{-1} \times \$19.10 \text{ hr}\right]. + \$52.89$ (for chipping, load^{-1});

   The weighted cost mile^{-1} factor, contained within the brackets, utilized the Forest Manual's cost mile^{-1} values of 0.4793 and 1.4380 for paved and unpaved roads, respectively (Ref. 20, p. 2422.41--18). The mechanics of calculating the above factor are as follows:

   $[(15.87)(0.33) + (10.43)(0.25)] \times 0.4793 \ \$ \text{ mile}^{-1} + [(18.62)(0.30) + (8.68)(0.12)] \times \$1.4380 \text{ mile}^{-1} = \$0.881954 \text{ mile}^{-1} \approx \$0.882 \text{ mile}^{-1}$.

   b) $\$604.00 - \$259.27 - \$34.06 - \$52.89 = \left[\frac{\text{distance (miles)}}{11.4722 \text{ mph}} \times \$0.882 \text{ mile}^{-1} \times \$19.10 \text{ hr}^{-1}\right]$, where travel costs are equal to $[\$0.882 \text{ mile}^{-1} \times 11.4722 \text{ miles hr}^{-1}] = \$29.22 \text{hr}^{-1} \text{ mile}^{-1}$ traveled.

   c) Thus, by dividing the residual price per load by the travel cost per hour, the total miles allowed for travel (and still break even on costs) can be calculated. The results of this calculation are shown below.

   "Haulage allowance" (in miles) = $\frac{\$257.78 \text{ load}^{-1}}{\$29.22 \text{ hr}^{-1} \text{ mile}^{-1}} = 8.8$ miles round trip.

TABLE 4-10.--Summary Calculations for the Revised Estimate of Economic Feasibility/Haulage Radius Determination Using the USDA Forest Manual Model

CRITICAL ASSUMPTION: The same as given in Table 4-9.

APPROACH:

1. Assume in-plant chipping and handling costs of \$3.50 green ton^{-1}.
2. Ceiling price per load: 27.5 green tons load^{-1} * \$40 green ton^{-1}.
3. Cost per green ton: \$17.17 * 0.75 = \$12.88.
4. Expression for calculating the economically feasible haulage radius:
    a) $\$1100.00 = \$354.20 + (1.516 * \$19.10\ \text{hr}^{-1}) + [\frac{\text{distance (miles)}}{17.2\ \text{mph}} * \$0.72\ \text{mile}^{-1} * \$19.10\ \text{hr}^{-1}] + \$96.25$ (for chipping, load^{-1}).

    b) $\$1100.00 - \$354.20 - \$28.96 - \$96.25 = [\frac{\text{distance (miles)}}{17.2\ \text{mph}} * \$0.72\ \text{mile}^{-1} \times \$19.10\ \text{hr}^{-1}]$, where travel costs are reduced to $[(0.72/0.882)(11.4722/17.2)(29.22)] = \$15.91\ \text{hr}^{-1}\ \text{mile}^{-1}$ traveled.

    c) Thus, the "haulage allowance" (in miles) is calculated below.

    "Haulage allowance" (in miles) = $\frac{\$620.59\ \text{load}^{-1}}{\$15.91\ \text{hr}^{-1}\ \text{mile}}$ 39.0 miles round trip.

TABLE 4-11.--Summary of Data Needs for Input into the R. Withycombe Cost Estimate Model (Expressed as 1981 Dollars per Green Ton)

	FOREST COVER AND FIBER TYPES			
	Lodgepole pine[a]		Douglas Fir[b]	
COMPONENT	Saw Timber	Logging Residues	Saw Timber	Logging Residues
Hand felling and limbing costs	9.28	48.98	6.08	51.32
Tractor skidding costs[c]	14.24	25.88	10.55	23.67
Loading/hauling costs[d]	7.25	8.57	6.65	8.29
Unloading costs[e]	3.37	5.27	3.16	5.12
Σ	$34.14	$88.70	$26.44	$88.40

Notes:

a) Assumes average 8.5" dbh for sawtimber and dbh size distribution for residues as given in Table 4-4. Costs are extrapolated from Table 1 in R. Withycombe, Ref. 13.

b) Assumes average 9.5" dbh for sawtimber and dbh size distribution for residues as given in Table 4-4. Costs are extrapolated from Table 1 in R. Withycombe, Ref. 13.

c) Assumes an average skidding distance of 825 feet, and dbh assumptions as above; costs are extrapolated from Table 3 in R. Withycombe, Ref. 13.

d) Assumes an average haul distance of 20 miles and road conditions similar to those utilized in the Forest Manual cost appraisals. Costs are extrapolated from Table 5 in R. Withycombe, Ref. 13.

e) Assumes the same dbh criteria for sawtimber and residues as in a) and b); costs are extrapolated from Table 8 in R. Withycombe, Ref. 13.

TABLE 4-12.--Summary Calculations for Estimating the Economically Feasible Haulage Distance, Using the Withycombe Model (in 1981 Dollars)

CRITICAL ASSUMPTION: The same as given in Table 4-9 (i. e., a \$40 green ton^{-1} ceiling on as-received wood feedstock).[a]

APPROACH:

1. Assume in-plant shipping and handling costs of \$3.50 green ton^{-1}.
2. Assumed ceiling price per load: a) \$604.00 for a 15.1 ton shipment, b) \$1100.00 for a 27.5 ton shipment.
3. Assumed resource costs per green ton: a) \$34.14 for lodgepole pine sawtimber; b) \$88.70 for lodgepole pine logging residues; c) \$26.44 for Douglas fir saw timber; and d) \$88.40 for Douglas fir logging residues.
4. The estimates for total haulage distances (in miles) judged to be economically feasible are summarized below.

	3a	3b	3c	3d
2a	<0	<0	~1.5	<0
2b	<1	<0	~5.9	<0

Note:

a) The following additional assumptions were utilized in the calculations: 1) an average speed of 14.336 mph and an operating cost of \$0.801 mile^{-1}; 2) loading/unloading times totaled to 1.783 hrs; and 3) a \$34.06 hr^{-1} cost for the log truck and driver, (extrapolated from Ref. 13, p. A-7, and adjusted to 1981 dollars.

TABLE 4-13.--Acres of Non-Federal Commercial Timberlands by Ownership Class and County

	OWNERSHIP CLASS				
County	Montana State	Forest Industry	Private	County and Municipal	Total Acres
Beaverhead	23,100	900	43,400	< 50	~ 67,450
Deer Lodge	21,500	1,400	50,500	< 50	~ 73,450
Granite	9,300	37,800	94,000	< 50	~ 141,150
Jefferson	6,600	1,000	82,600	--	90,200
Powell	29,400	81,200	157,700	< 50	~ 268,350
Silver Bow	9,100	200	34,100	< 50	~ 43,450
TOTAL ACRES	99,000	122,500	462,300	<250	~ 684,050

SOURCE: Ms. Dorothy Felt, Reference 33.

TABLE 4-14.--Recent Timber Harvest Statistics for Private, Montana State, and Federal Lands Within and Adjacent to the Study Area (in MBF)

	YEAR[a]							
	1976		1977		1978		1979	
County	Private[b]	State	Private[b]	State	Private[b]	State	Private[b]	State
Beaverhead	5,452	0	9,045	-	11,725	0	3,988	0
Deer Lodge	7,387	0	31	-	1,620	0	201	0
Granite	21,066	0	27,020	-	22,935	52[c]	11,340	0
Jefferson	11,769	0	7,390	-	10,844	0	4,269	0
Powell	32,205	2,450	34,018	-	42,726	81[c]	54,451	1,267[c]
Silver Bow	297	0	98	-	2,246	0	1,525	0
Σ	78,176	2,450	77,602	Not Available	92,096	133	75,774	1,267
Bureau of Land Management								
Dillon S.Y.U.	0		500		1,000		1,000	
Missoula S.Y.U.	3,770		3,000		4,000		6,000	
Beaverhead National Forest[d]								
Wisdom R.D.	~ 0		2,296		1,585		2,299	
Wise River R.D.	~ 0		6,347		3,352		373	
Deer Lodge National Forest[d]								
Butte R.D.	183		7,688		5,666		1,662	
Deer Lodge R.D.	12,724		643		2,544		3,242	
Philipsburg R.D.	1,872		5,383		2,311		12,378	

NOTES:

a) Private lands data given in calendar years, Montana State lands data given in fiscal years (i.e., 6/30-7/1), federal lands data given in fiscal years (i.e., 10/1-9/30).
b) Includes both industrial and non-industrial private lands.
c) Does not include post/pole or rail harvests or other types of cutting permits.
d) Data represents harvested volume for BLM and Beaverhead N.F., sold volume for the Deer Lodge N.F.

SOURCE: Private and Montana State lands (44); Bureau of Land Management lands (45); Beaverhead National Forest lands (46); Deer Lodge National Forest lands (47).

TABLE 4-15.--Estimated Timber Harvest Acreages[a] and (Estimated Percentage of Total CFLS)[b] For Private, Montana State and Federal lands Within and Adjacent to the Study Area

County	1976 Private	1976 State	1977 Private	1977 State	1978 Private	1978 State	1979 Private	1979 State
Beaverhead	727 (1.64)	0 (0)	1,206 (2.72)	-	1,563 (3.53)	0 (0)	532 (1.20)	0 (0)
Deer Lodge	985 (1.90)	0 (0)	4 (0.01)	-	216 (0.42)	0 (0)	27 (0.05)	0 (0)
Granite	2,809 (2.13)	0 (0)	3,603 (2.73)	-	3,058 (2.32)	7 (0.07)	1,512 (1.15)	0 (0)
Jefferson	1,569 (1.88)	0 (0)	985 (1.18)	-	1,446 (1.73)	0 (0)	569 (0.68)	0 (0)
Powell	4,294 (1.80)	327 (1.11)	4,536 (1.90)	-	5,697 (2.38)	11 (0.04)	7,260 (3.04)	169 (0.57)
Silver Bow	40 (0.12)	0 (0)	13 (0.04)	-	299 (0.87)	0 (0)	203 (0.59)	0 (0)
Σ	10,424 (1.78)	327 (0.33)	10,347 (1.77)	Not Available	12,279 (2.10)	18 (0.02)	10,103 (1.73)	169 (0.19)
Bureau of Land Management								
Dillon S.Y.U.	0 (0)		67 (0.04)		133 (0.08)		133 (0.08)	
Missoula S.Y.U.	503 (0.50)		400 (0.40)		533 (0.53)		800 (0.80)	
Beaverhead National Forest								
Wisdom R.D.	~ 0 (~0)		306 (0.15)		211 (0.10)		306 (0.15)	
Wise River R.D.	~ 0 (~0)		846 (0.79)		447 (0.42)		50 (0.05)	
Deer Lodge National Forest								
Butte R.D.	24 (0.02)		1,025 (1.05)		755 (0.77)		222 (0.23)	
Deer Lodge R.D.	1,696 (1.94)		86 (0.10)		339 (0.39)		432 (0.49)	
Philipsburg R.D.	250 (0.10)		718 (0.30)		308 (0.13)		1,650 (0.68)	
Σ	2,473 (0.24)		3,448 (0.34)		2,726 (0.27)		3,593 (0.36)	

Notes:

a) Assumes an average volume of 7500 board feet acre^{-1} (see Section 4.2.2.2 for rationale).

b) See Montana State and private CFL data in Table 4-13, plus accompanying text for federal CFL data.

Sources: Private and Montana State Lands (44); Bureau of Land Management lands (45); Beaverhead National Forest lands (46); Deer Lodge National Forest lands (46).

TABLE 4-16.--Relative Trends in Timber Harvest (in MBF) on National Forest Lands Versus Private Lands Within the General Study Area, 1969-1976

	CALENDAR YEAR							
PRIVATE LANDS BY COUNTY	1969	1970	1971	1972	1973	1974	1975	1976
Beaverhead	--	--	31	--	864	9,059	4,160	5,452
Deer Lodge	194	13,505	8,163	1,493	474	511	546	7,387
Granite	19,095	16,259	10,527	18,885	23,377	14,531	9,321	21,066
Jefferson	895	2,700	2,434	3,734	3,667	4,466	3,607	11,769
Powell	26,766	30,800	26,407	37,816	51,639	38,482	46,041	32,205
Silver Bow	566	--	--	--	--	--	17	297
Σ	47,516	63,264	47,562	61,928	80,021	67,049	63,692	78,176
NATIONAL FOREST LANDS								
Beaverhead	25,375	17,504	19,059	16,795	28,615	10,664	11,560	11,359
Deer Lodge	22,977	25,346	46,473	22,856	23,888	21,578	17,682	16,681
Helena	17,630	16,710	14,102	13,912	27,714	12,798	8,130	6,577
Σ	65,982	59,560	79,634	53,563	80,217	45,040	37,372	34,617

Sources: Reference 44, for private lands; Reference 50 for national forest lands.

TABLE 4-17.--Timber Volume Sold or Projected for Sale on Selected National Forests For Fiscal Years 1981-2010 (in MBF)[a]

National Forest Lands	FISCAL YEAR							
	1981	1982	1983	1984	1985	1986-1990	1991-2000	2001-2010
Beaverhead	~ 23,000	22,000	24,000	24,000	25,000	31,000	36,000	40,000
Deer Lodge	~ 18,000	15,000	17,000	17,000	18,000	25,000	30,000	34,000
Helena	12,065	15,000	17,000	19,000	20,000	26,000	30,000	34,000
Σ	~ 53,065	52,000	58,000	60,000	63,000	82,000	96,000	108,000

Note:

a) Projections for FY82-2010 utilize the Resource Policy Act (RPA) high projections.

Sources: Reference 51 for FY81 data; Reference 35, pp. 139, 145, 151 presents the FY82-2010 projections.

TABLE 4-18.--Forest Habitat or Community Types Present by Land Use Class Within the Deer Lodge National Forest (in Acres)

HABITAT TYPE GROUPING; "DRY DOUGLAS FIR SITES"[a,b]

Land Use Class[c]	Psme/Caru	Psme/Cage	Psme/Spbe	Psme/Aruv	Psme/Arco	Psme/Syor	Σ
500	51,376	210	0	0	60	80	51,726
600	93,193	370	25	0	967	0	94,555
700	62,742	295	75	0	280	0	63,392
Σ	207,311	875	100	0	1,307	80	209,673

HABITAT TYPE GROUPING: "MOIST DOUGLAS FIR SITES"[a,b]

Land Use Class[c]	Psme/Phma	Psme/Vagl	Psme/Libo	Σ
500	815	6,767	5,903	13,485
600	1,184	2,502	11,245	14,931
700	7,637	3,758	6 002	17,397
Σ	9,636	13,027[d]	23,150	45,813 (plus 6,200 acres of mixed spruce/ Douglas fir/Lodgepole pine = 52,013 acres)

Notes:
- a) Descriptions of the various habitat types can be found in R. D. Pfister _et al_., Reference 52.
- b) Habitat type grouping is related to fuel loading and habitat type fire groups as discussed in Brown and See, Reference 16.
- c) LUC Series 500 is the non-reserved standard component; the "objective of Silvicultural prescription will be to maximize forest products realization with proper site protection" (Reference 27, p. 3). Production from LUC Series 600 (Special Component--Non-Reserved) will vary from full potential yields to salvage and sanitation cutting only (Reference 27, p. 4). The LUC Series 700 is the Marginal Component Non-Reserved. "This is the portion of the regulated commercial forest land that is not included in standard or special primarily because of excessive development cost, low product values, or resource protection requirements", as defined in the _Forest Service Manual_, Section 2412.15 (Reference 27, p. 11).
- d) Represents a 50:50 ratio between Douglas fir and lodgepole pine, in terms of percent crown cover.
- e) Representa a 50:50 ratio between subalpine fir and Douglas fir, in terms of percent crown cover.
- f) Represents a 50:50 ratio between subalpine fir and lodgepole pine, in terms of percent crown cover.

Sources: See References 26 and 27.

TABLE 4-18.--Forest Habitat or Community Types Present by Land Use Class Within the Deer Lodge National Forest (in Acres) (Continued)

COMMUNITY TYPE GROUPING: LODGEPOLE PINE SITES, SPECIES CROWN COVER GREATER THAN 80 PERCENT[a,b]

Land Use Class[c]	Abla/ Vaca	Abla/ Libo	Abla/ Mefe	Abla/ Xete	Abla/ Vagl	Abla/ Vasc	Abla/ Alsi	Abla/ Arco	Abla/ Cage	Σ
500	7,343	8,428	13,239	36,098	2,085	50,945	90	29	0	118,257
600	8,016	11,231	10,176	15,107	1,907	75,420	210	146	275	122,488
700	1,410	11,161	10,815	17,429	2,061	49,009	296	559	0	92,740
Σ	16,769	30,820	34,230	68,634	6,053	175,374	596	734	275	333,485

HABITAT TYPE GROUPING: "SUBALPINE FIR SITES, LODGEPOLE PINE CROWN COVER < 50 PERCENT[a,b]

Land Use Class[c]	Abla/Gatr	Abla/Caca	Abla/Caru	Abla/Clps	Σ
500	415	1,300	10	15	1,740
600	2,855	2,408	42	0	5,305
700	1,530	1,196	428	245	3,399
Σ	4,800[e]	4,904[f]	480	260	10,444

Notes:
- a) Descriptions of the various habitat types can be found in R. D. Pfister et al., Reference 52.
- b) Habitat type grouping is related to fuel loading and habitat type fire groups as discussed in Brown and See, Reference 16.
- c) LUC Series 500 is the non-reserved standard component; the "objective of Silvicultural prescription will be to maximize forest products realization with proper site protection" (Reference 2, p. 3). Production from LUC Series 600 (Special Component--Non-Reserved) will vary from full potential yields to salvage and sanitation cutting only (Reference 27, p. 4). The LUC Series 700 is the Marginal Component Non-Reserved. "This is the portion of the regulated commercial forest land that is not included in standard or special primarily because of excessive development cost, low product values, or resource protection requirements", as defined in the Forest Service Manual, Section 2412.15 (Reference 27, p. 11).
- d) Represents a 50:50 ratio between Douglas fir and lodgepole pine, in terms of percent crown cover.
- e) Represents a 50:50 ratio between subalpine fir and Douglas fir, in terms of percent crown cover.
- f) Represents a 50:50 ratio between subalpine fir and lodgepole pine, in terms of percent crown cover.

Sources: See References 26 and 27.

TABLE 4-19.--Timber Harvest Groupings (Relative Proportions of the CFL Base), and Subsequent Estimates of Shelterwood vs. Clearcutting Within a 25-Mile Radius of Anaconda (in Acres)

A. HARVEST GROUPINGS	LOW ESTIMATE	HIGH ESTIMATE
1. "High elevation" subalpine fir types (0.0000)[a]	0	0
2. "Low elevation" Douglas fir types (Caru, Cage, Spbe, Aruv, Arco, Syor); 0.2597,[b] 0.0866[c]	54,274[b] 18,098[c]	82,756[b] 27,596[c]
3. Douglas fir/bunchgrass (warm) sites; 0.0000[c]	0	0
4. Douglas fir cool sites (Vagl, Phma, Libo); 0.0859[c]	17,952[c]	27,373[c]
5. Subalpine fir cool sites (Caca, Gatr, Caru, Clps); (0.0172)[c]	3,595[c]	5,481[c]
6. Lodgepole pine dominated sites (Vaca, Libo, Mefe, Xete, Vagl, Vasc, Alsi, Arco, Cage); (0.2753,[b] 0.2753)[c]	57,534[b] 57,534[c]	87,727[b] 87,727[c]

B. SHELTER WOOD VS. CLEARCUT ACRES YEAR^{-1} WITHIN THE STUDY AREA (SUMMARY)[d]

1. Shelter wood cut: 1,030 to 1,571 acres.

2. Clearcut: 1,185 to 1,807 acres.

Notes: a) Proportions calculated using the data from Table 4-18.

b) Clearcutting removes approximately 100 percent of the merchantable biomass acre.$^{-1}$

c) Shelter wood cutting removes about 60 percent of the biomass acre^{-1} in the first cut, while the the remainder is harvested approximately 20 years later.[54] The proportion of clearcut to shelter wood cut was assumed to be 75:25 and 50:50 for harvest groups 2 and 6, respectively; groups 4 and 5 were designated to shelter wood cutting only.

d) The long-term rate of access was calculated as the mean of 0.85 percent year $^{-1}$ (i.e., 1976) plus 1.5 times this mean (i.e., 1.275 percent) in 2010, for a value of 1.06 percent year.$^{-1}$

TABLE 4-20.--Estimated Variability in Logging Residue Production Within the 25-Mile Radius Study Area (in Green Tons per Year)[a]

		LOW ESTIMATE		HIGH ESTIMATE	
Harvest Group		Clearcut	Shelter Wood	Clearcut	Shelter Wood
2		7,019	1,404	10,702	2,141
4		--	1,393	--	2,124
5		--	434	--	662
6		20,125	12,075	30,687	18,412
	Σ	27,144	15,306	41,389	23,339
		ΣΣ 42,450		64,728	

Note: a) See Table 4-19 for explanation of harvest group terminology, plus necessary data and assumptions utilized in making the above calculations.

TABLE 4-21.--Summary of Phone Interviews with Pertinent (Regional) Sawmill Plus Post and Pole Operators

A. SAWMILLS

County	Firm	Size Class[a]	Comments
Beaverhead	F. H. Stoltze Land and Lumber Co., Dillon	D	The coarse and fine mill wastes are sold to the Champion International (C. I.) linerboard operations located at Frenchtown, Montana. A "minimal amount" of bark remains uncommitted.
	Wilke Brothers Sawmill, Wisdom	A	Small tonnages are currently generated, and are "dumped on adjacent farmer's fields."
Broadwater	Wickes Forest Industries, Townsend	D	C. I. has constructed a reload facility for rail haulage of chips and sawdust to their Frenchtown operations. The Louisiana Pacific (L. P.) particle board plant (Missoula) has contracted for the planer shavings. The Wickes' hogfuel is sold to a decorative bark manufacturing firm, with their excess then resold to C. I. for steam generation.
Granite	Hall Lumber Co., Hall	B	About 35 dry tons per day are trucked to the C. I. Frenchtown operations. An unspecified amount of bark is also shipped for C. I.'s use as hogfuel. The sawdust and planer shavings are committted to the LP Missoula operation.
	Ray Lucier Sawmill, Maxville (Retired operator)	A	Although no records were kept, Mr. Lucier thought "hundreds of tons per year" of wastes were produced; they were usually dozer piled and then burned. In the recent past, C. I. offered to construct a collector bin for acquisition of sawdust and planer shavings.

TABLE 4-21.--Summary of Phone Interviews with Pertinent (Regional) Sawmill Plus Post and Pole Operators (Continued)

County	Firm	Size Class[a]	Comments
Powell	Deer Lodge Wood Products, Inc., Deer Lodge	A	The sawdust is used locally by the State Prison Farm and local ranchers for animal bedding. The slabs from rough cutting 4 x 4 in. and 8 x 8 in. lumber are burned for space heating. The owner's wife expressed doubt as to the long-term availability of a large, uncommitted residue supply.
	Louisiana Pacific Corp., Deer Lodge	E	Their total wastes are chipped, then either sent to their Missoula operations or sold to C. I. for hogfuel. "This arrangement will expectedly continue into the future."
Silver Bow	Arthur Dick Sawmill, Butte	A	Approximately 10 tons per day of fine and coarse mill wastes plus "three truck loads" of barkwood are produced from pole peeling operations per day. They are currently negotiating with C. I. for sale of these wastes.
B. POST AND POLE PROCESSORS		Plant Type[b]	
Beaverhead	Raymond Weaver Post and Pole, Wisdom	-	About 15 to 20 tons per day of chips containing bark are produced from pole peeling operations; as they aren't committed, disposal usually involves dozer piling followed by burning.
Granite	Granite Timber and Treating Plant, Philipsburg	-	An estimated 10 to 15 tons per day of all wastes are produced. The slabs are either burnt at the mill or bundled and sold locally for residential space heating. The wastes are not committed to C. I. or any other large operation.

TABLE 4-21.--Summary of Phone Interviews with Pertinent (Regional) Sawmill Plus Post and Pole Operators (Continued)

County	Firm	Plant Type[b]	Comments
Jefferson	Pipestone Post and Pole, Whitehall	T-NP	An estimated 20 to 30 tons per year of wood/bark chips are produced. These wastes are not committed to other uses (e.g., C. I.)
	Robbins Posts, Whitehall	CS-NP	No mill wastes are produced.
Silver Bow	Montana Pole and Treating Plant, Butte	P	The startup of sawmill operations could generate about 10 tons per day (assuming a good market). C. I. has already offered to purchase the wastes for hogfuel.

Notes:

a) Interpretation of size classes as follows: A = less than 3,000 MBF per year, B = 3,000-5,000 MBF per year, D = 10,000-25,000 MBF per year, E = 25,000-50,000 MBF per year.

b) Interpretation of treatment type: CS = cold soak; NP = non-pressure; P = pressure; T = thermal.

Source: Phone interviews conducted by the author on October 1 and 5, 1981.

TABLE 4-22.--Sawmill and Plywood Plant Mill Residue Production (1976) Within the General Study Area (in Bone-Dry Units)[a]

	COUNTY GROUPINGS	
MILL RESIDUE TYPE	Beaverhead, Gallatin, Madison	Granite, Powell, Ravalli, Silver Bow
Bark:		
Unused	6,574	16,879
Used		
Hogfuel	7,885	9,759
Other	-----	1,182
	14,459	27,820
Fine Residue:		
Unused	5,864	10,822
Used		
Hogfuel	6,177	14,525
Board Plants	-----	------
Pulp/Paper	10,611	18,238
Other	------	------
	22,652	43,585
Coarse Residue:		
Unused	1,825	960
Used	-----	------
Hogfuel	827	------
Pulp/Paper	17,618	39,916
Other	827	------
	21,097	40,876
RESIDUE TOTALS		
Unused	14,263	28,661
Used	43,945	83,620

Note: a) One bone dry unit equals 2400 pounds oven dry weight or approximately 4,800 "green" pounds.

Source: Mr. Charles Keegan III, Ref. 56

TABLE 4-23.--Summary of Solid Waste Transport Costs from Local Landfill Sites to the FGE Facility (in 1981 Dollars Per Ton)

LANDFILL LOCATION (MILES FROM FGE SITE*	HAUL METHOD	
	Roll-off Container[a]	Transfer Trailer[b]
Anaconda (3)*	2.62	1.68
Butte (27)*	23.60	15.09
Deer Lodge (26)*	22.72	14.53

NOTES:

a) Assumes the use of a 40 cubic yard compacted roll-off container truck having a crew size of 1 and haulage capacity of 10 tons; general operating costs were set at $1.47 per mile, while round-trip haul costs were set at $0.29 per ton per mile.

b) Assumes the use of a 65 cubic yard transfer tailer having a crew size of 1 and haulage capacity of 18 tons; general operating costs were set at $1.61 per mile, while round-trip haul costs were set at $0.19 per ton per mile.

SOURCE:

The costs (in 1976 dollars) were taken from Table A-6 from Ref. 59; they were adjusted to 1981 dollars using 1976 and estimated 1981 wholesale price indices of 183.0 and 295, respectively.

TABLE 4-24.--Summary of Resource Inventories for the 25-Mile Radius Study Area Expressed in Units of Green Tons Per Year

	AVAILABILITY ESTIMATE	
FEEDSTOCK COMPONENT	Low Estimate	High Estimate
Logging Residues[a]	27,592 (28.9)[d]	42,073 (44.1)
Mill Residues[b]	17,170 (18.0)	25,754 (27.0)
Wood Fiber Recovery/Recycling[c]	6,390 (6.7)	9,060 (9.5)
Σ	51,152 (53.6)	76,887 (80.6)

Notes:

a) Assumes 65 percent availability of the values given in Table 4-20; the rationale for reducing the totals in the face of competition with residential wood users is discussed in Subsection 4.3.2.2.

b) See subsection 4.3.1.2 for the derivation of these estimates.

c) The low estimate represents an average of the 1981 and 1990 Class III waste projections of solid waste production within the study area using 1976 study data; 1980 study data was utilized to prepare the high estimate. Subsection 4.3.2.1 offers discussions on the derivations of these estimates.

d) The figures in parantheses are percentages of total annual green ton requirements for FGE production alone for a 2.5 million GPY production facility.

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5.0 ECONOMIC ANALYSIS

Analysis of the operating economics of the plant has been done on an annual basis. Initial investment consists of the total installed cost of the facility of $11,847,000 plus an additional $592,000 (5% of plant costs) for working capital. Unit cost and quantities of inputs are listed in Table 5-1, as are the estimated quantities and unit prices of alcohol and saleable by-products. All daily quantities are multiplied by 330 to reach annual production figures.

Estimates of profit before allowance for taxes and interest payments have been made using waste wood feedstock costs of $30, $40, and $50 per ton (Table 5-2). Only the wood waste price was varied since it dominates all other input costs (at $30/ton the feedstock makes up 56% of the total operating costs). Upon performing a cursory analysis it was immediately obvious that the two higher wood waste prices are not feasible since they result in substantial losses even before any allowance for taxes and interest expense is considered.

The next step in the analysis proceeded using $30/ton as the single wood waste cost considered. Interest costs were evaluated assuming funds would have to be borrowed to cover both the plant costs and the working capital costs. Because interest rates have been so volatile for the past few years, one cannot help but be skeptical of any rate chosen; 12% was chosen as an approximate but hopefully realistic estimate of future interest costs.

Total funds borrowed will be $12,439,251 (Table 5-3, Part A, I). Assuming a loan payback schedule of 20 equal year-end payments and a twelve percent rate of interest, average annual interest costs will be $1,043,390 over the 20 year period (Table 5-3, Part A, II). This results in an estimated before tax loss of $343,000 annually.

Keeping the feedstock price at $30 per ton, the interest rate was varied to determine what interest rate was required to produce a break-even result. The facility would break-even if the interest was approximately 8 3/4% (Table 5-3, Part A, III). This, of course, is well below current market rates of interest andis not a reasonable estimate of the level of interest rates for the near future.

Finally, the 12% interest rate scenario was reworked with wood waste cost varied to determine that cost per ton which would allow break-even operation while paying the more realistic interest rate. The resulting cost was $26.50 per ton (Table 5-3, Part B, I).

TABLE 5-1.--Fuel Ethanol Production from Wood Waste

2.5 Million GPY
330 Day Operating Year

PLANT INPUTS

Wood Waste	305 green tons/day @ $30-40-50 T
*Sulfuric Acid	8.4 tons/day @ $74.25 T
*Hydrated Lime	4.77 tons/day @ $42.50
Electricity	54,528 KWH/day @ 0.039 KWH
Coal (Rosebud)	63.5 tons/day @ $20.00 T
**Water	500,000 gal/day @ 0.70 Mgal

PLANT OUTPUTS

*Ethanol, Anhydrous	7,600 gal/day @ $2.00 gal
*Methanol, Anhydrous	364 gal/day @ $0.75 gal
*Furfural, Tech. Grade	3,000 lb/day @ $0.66 lb

* Price Basis: Chemical Marketing Reporter, November 16, 1981.

**Price Basis: Butte Water Company, Industrial Rate, November 30, 1981.

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TABLE 5-2.--Estimated Annual Operating Costs, Gross Revenues and Profit Before Taxes and Interest Expense (in Thousands of Dollars)

Estimated Operating Costs:			
Wood Waste Costs ($/green ton)	$30	$40	$50
Wood Wastes (100,650 tons)	$3020	$4026	$5033
Sulfuric Acid (2,772 tons)	$ 206		
Hydrated Lime (4,574 tons)	$ 67		
Electricity (17,994 MWH)	$ 702		
Coal (20,955 tons)	$ 419		
Water (165,000,000 gal.)	$ 116		
Labor (10 people)	$ 298		
Depreciation (20 years, straight line)	$ 592		
Total Operating Costs	$5420	$6426	$7433
Estimated Annual Revenues:			
Anhydrous Ethanol (2,500,000 gal.)	$5000		
Anhydrous Methanol (120,000 gal.)	$ 90		
Tech. Grade Furfural (990,000 lbs.)	$ 653		
Syrup (3,960 tons)	$ 277		
Gross Revenue	$6020	$6020	$6020
Net Profit or (Loss) before Interest and Taxes	$ 700	($ 406)	($1413)

TABLE 5-3.--Capital Cost and Alternative Interest Scenarios
(All Figures are in Thousands of Dollars)

A. Wood Wastes at $30/Ton

I. Capital Requirements

Plant Costs	$11,847
Operating Capital	$ 592
Total	$12,439

II. Alternative Estimates of Interest Costs and After Interest Profit

(1) Interest Expenses and Profits; 20 Year Loan at 12% Interest Rates:

Average Annual Interest Expense	$ 1,043
Average Annual Principal Repayment	$ 622
Total Annual Loan Payment	$ 1,665
Profit Before Interest Expense	$ 700
Interest Expense	$ 1,043
Profit (Loss) Net of Interest	($ 434)

III. Break Even Rate of Interest:

Interest Rate Which Generates $700 Average Annual Interest Expense = 8.75% (approximate)

B. Wood Waste Price Allowed to Vary

I. Break Even Wood Waste Cost with 12% Interest Rate = $26.50/Ton

6.0 CONCLUSIONS AND RECOMMENDATIONS

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6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS ON TECHNICAL AND ECONOMIC FEASIBILITY

Fuel ethanol production at Anaconda, Montana, was found to be technically feasible by employing the Madison Wood Sugar Process coupled with conventional fermentation and distillation systems. A preliminary design was prepared for the subject plant, incorporating current technology through all unit operations. By the inclusion of modern equipment and provisions for unit automation, a considerably more reliable and efficient plant resulted as compared to the original Madison process plant of World War II vintage.

Bark contents of the wood waste feedstock will have a marked effect upon the alcohol yield efficiency of this plant, since tree barks in general contribute little to the alcohol production from wood waste. This problem was addressed in perfecting the preliminary plant design, to maximize ethanol yield from the feedstock. Steam explosion equipment was designed into the plant for this purpose, to incorporate physical and chemical changes in the incoming wood stream through autohydrolysis and to effect manifold magnification of particle surface exposure prior to the conventional acid percolation-hydrolysis step of the Madison Wood Sugar Process.

A total plant capital investment, including land, of $11,847,000 would be required in 1981 U. S. dollars, for the plant rated at 2.5 million gallons annual production capacity. The total plant cost figure resulted from detailed estimates by individual plant components through direct contact with equipment suppliers and by application of the Richardson plant construction standards.[1] Findings on plant costs are consistent with other published estimates for similar wood-to-ethanol plants, when plant production capacity and annual inflation rates are considered.

Detailed study and assessment of wood waste resources available for a fuel ethanol plant at Anaconda revealed that wood waste supplies were inadequate, at least for a plant producing 2.5 million gallons of anhydrous alcohol per year. In fact, a maximum of 87 percent of the plant's requirement would be available, for alcohol production alone. An operating radius of 25 miles was found to be realistic, in economic terms, for wood waste gathering and hauling to the plant.

Some critical features were pinpointed for the reliability of wood waste supply volumes for an ethanol plant, over its useful life, perhaps made more obvious by events during the particular time period in which the wood resources survey took place. The following factors are apparent from the survey findings:

A. In considering the safety of investment in the subject plant, a factor of singular importance is the recognition that its primary feedstock supply is the refuse byproduct of the logging and sawmilling industries. Therefore, the ethanol plant functions unavoidably in an umbilical relationship with these waste producing industries, relying entirely upon the level of logging and milling activity at any given time to dictate the total amount of wood waste available for the various uses that are made of it. Reminders of the seriousness of this factor have been numerous during the course of the resource study, when national economic conditions have forced drastic curtailment of logging, milling, and pulping activities.

---

[1] Process Plant Construction Estimating Standards, Volumes 1-4, Richardson Engineering Service, Inc., 1981.

B. Competition for the available wood waste supply is a matter of substantial consequence. In the resource study area for this plant it became apparent that removal of wood waste for plywood and chipboard manufacture has escalated markedly in recent years, along with increased utilization for boiler fuel among paper manufacturers. Industrial users are by no means the only serious competition for wood waste, because of rapid increases in demand for saw logs by individual citizens for home heating.

When published study findings on residential use of firewood from other Montana areas were extrapolated to the Butte-Anaconda area, it was found to be conceivable that upwards of half the total wood residue in the study area may be requested for private use. Given the national trends of increasing fossil fuel costs and expansion of wood use for home heating, it is possible that homeowners will take precedence in time over industrial users when wood waste resources are allocated from public lands.

C. Changing conditions in the national economy, and particularly in energy costs and liquid fuel supply-demand ratios, will continue to present a fundamental question for wood-to-ethanol processing; viz., whether it is more favorable economically and in energy economy to harvest the energy from wood waste directly through combustion or by conversion to fuel ethanol through chemical processing.

Economic analysis of the potential business to be created by operation of the subject plant did not result in a forecast of profitability under economic conditions that could be foreseen at the time of the analysis. The total capital requirement for plant ownership and operation was estimated to be $12,439,251, and it was assumed as a base case that all funds would be borrowed at 12 percent interest rate with a 20-year loan payback schedule. With these parameters in place, the business was forecasted to lose $343,000 annually. Break-even analyses of economic data, holding all other factors of the base case constant and varying interest rate alone, revealed business break-even at 8.75 percent interest rate. Similarly, with the base case held constant and wood waste cost varied, break-even was forecasted at a feedstock cost of $26.50 per ton. This feedstock cost compares with $30.00 per ton found to be realistic for forest resource conditions affecting a plant situated at Anaconda, Montana.

The findings through economic analysis on the subject plant should not be extrapolated literally to other potential plant locations in Montana. In fact, the combined factors of preselected plant site and plant production capacity served to magnify problems in wood resource quality and quantity that are somewhat unique. Since feedstock costs were shown to be the single most dominant feature of plant economics, representing 56% of total operating costs in the base case, feedstock conditions at the Anaconda site exerted a major influence on negative profitability forecasted for the plant.

Plant operating radius (i.e., the wood waste gathering radius necessary to sustain plant production) is the major controlling variable in determining delivered feedstock cost, largely because of freight costs involved. Therefore, both quality and quantity of wood waste available in a given area become critical economic features in potential plant site selections.

Other wood resource bases in Montana may have the potential to present improved profitability capabilities in a wood-to-ethanol plant venture. Thompson Falls, Libby, Dillon, and Phillipsburg appeared to offer considerably more attractive resource characteristics, from summary figures examined in this study. It should be emphasized, however, that none of these wood resource centers were examined with the detail, depth, and precision focused upon the Anaconda plant site.

6.2 RECOMMENDATIONS

The preliminary plant design devised in this study is satisfactory for installation in forested sections of Montana in general. This plant design should be kept intact as a package unit for examination of other areas in the state where improved conditions of potential profitability may exist.

Wood waste resource bases in Montana should be examined in detail to locate potential plant sites offering substantially higher levels and higher quality of wood waste availability than those presented by an assumed Anaconda, Montana plant site. Delivered feedstock cost will be a most important variable in plant economics. Moreover, feedstock gathering radius will be a controlling variable in that expense because freight costs make up such a high proportion of the total delivered cost for plant feedstock. Methods described in this report for systematic estimation of radius of economic feasibility should be applied when other forest resource bases are examined as potential plant sites for fuel ethanol production from wood wastes.

In judging adequacy of wood resources for a potential plant site, due consideration must be given to the definition of an acceptable margin of safety to ensure likelihood of plant operation during periods of low logging and milling activities. Developments in recent times, whereby these industries have been drastically suppressed, underline the need for careful attention to this factor.

In projecting feedstock requirements over an expected plant life, competitive forces at work in wood waste demand in a forest area should be assessed with a stringent view. In particular, careful attention should be directed to the trend for increasing demands on wood waste supplies for home heating fuel. This well established trend is a reasonably recent addition to wood waste supply-demand circumstances, and was found to represent a competition factor of no mean proportions in this study. This factor, coupled with the requirements of other industrial users of wood resources, suggests that long-term feedstock requirements for wood-to-ethanol plants may place those plants some safe distance from centers of human population.

Plant production capacity should be optimized to fit the wood resource base, and certain minor alterations in the preliminary plant design may be in order after a more highly acceptable plant location has been selected. For example, improvements in long-term plant operating costs may be possible by substitution of a wood-fired boiler system for the coal-fired system required for the Anaconda, Montana plant siting case studied here. The resource base, of course, would have to be present to justify this change in expected design requirements.

VOLUME II

Preliminary Plant Design and Estimated Plant Costs

MULTITECH

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7.0 MODIFICATIONS OF THE MADISON WOOD SUGAR PROCESS

7.1 INTRODUCTION

The original Madison wood sugar process,[1] which offered glucose yield improvements over the basic Scholler process,[2] relied upon direct introduction of ground wood stock to digestion chambers for hydrolysis with a mineral acid solution. The Madison improvement consisted essentially of reduced steam requirements at the digestion stage and lower sugar decomposition rates; thus an increase was gained in overall sugar recovery and subsequent ethanol yields.

An alcohol yield problem inherent in the Scholler process, and brought forward into the Madison process, was the very low alcohol yield potential of the bark component in wood waste feedstocks. Pilot plant tests conducted by Harris and Beglinger[1] as process development leading to the Madison process quantified the ethanol yield potential of Douglas fir bark. When their digester feed contained 25 percent bark, oven dry basis, only 7 percent of the alcohol yield obtained was derived from bark. Conversely, 93 percent of total alcohol yield resulted from bark-free wood.

In the plant complex considered here, it is anticipated that wood waste feedstock delivered to the plant will vary widely in its composition, and particularly in bark content. Therefore, maintenance of maximum alcohol yield will be under pressure continuously because of feedstock bark percentages alone. This condition emphasizes the need for a high level of processing efficiency to ensure upper limit recovery of alcohol values from non-bark feedstock components.

7.2 AUTOHYDROLYSIS PRETREATMENT

In developing the preliminary plant design for this complex, particular attention was concentrated upon methods of front-end processing to maximize availability of free cellulose for hydrolysis to glucose. Steam explosion equipment was selected for wood waste pretreatment to effect physicochemical separation of lignocellulose components and autohydrolysis of the cellulose fraction[3] in advance of delivery to digesters in the basic Madison process. The steam pretreatment processing step in the preliminary plant design is presented schematically in Section 9.0 as plant section B.

Lignocellulosic materials undergo physical and chemical changes when subjected to high pressure steam for a specific period of time. The changes that take place have been called autohydrolysis, because acetyl groups normally existing in the chemical makeup of the hemicellulose fraction catalyze the hydrolysis of this fraction. The summary effect is disruption of the structure of natural lignocellulose, making the cellulose fraction more highly susceptible to subsequent hydrolysis.

Quite aside from the chemical changes that take place, a valuable advantage of steam explosion is the rapid conversion of dense wood chips or sawdust to a near fluffy consistency, with highly magnified surface area exposure for reagent attack. Along with the chemical benefits of autohydrolysis, this feature of steam explosion pretreatment allows for minimum residence time in the succeeding hydrolysis step, thereby minimizing glucose destruction.

7.3 LIME NEUTRALIZATION

The original Madison wood sugar process[1] employed a system for lime handling and hydrolysate neutralization that was the state-of-the-art at the time but would be considered archaic by standards of current processing technology.[4] It utilized unslaked lime (CaO) as the neutralizing agent, which dictated the installation of cumbersome lime slaking equipment which delivered lime water slurry to the acid hydrolysate stream for neutralization. Given the natural hygroscopic tendency of unslaked lime, caking problems in storage and handling equipment could be expected as routine. Under these circumstances, the lime slaking operation would be expected to present an unnecessary labor demand and a somewhat unpredictable dilution factor for the neutralization reaction.

Facilities and equipment for lime storage, slurry preparation, and delivery were considerably streamlined in the preliminary plant design presented here. This portion of the plant system is shown schematically in Section 9.0 as part of plant section E.

Briefly stated, the lime slaking system is replaced with a simplified process utilizing in-line static mixers in tandem. Hydrated lime is the neutralizing agent, taking advantage of its free flowing characteristics. Vena contracta units precede static mixers, each operated with a single pump, to pull lime and acidified sugar solution into the system by venturi effect. Use of these units will allow continuous preparation and delivery of lime slurry for neutralization, without the pulsations in lime:water ratios common to conventional lime slaking equpment and consequent variations in dilution of sugar solutions in the neutralization step.

7.4 LITERATURE CITED -- SECTION 7.0

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2. Scholler, H., Saccharifying Cellulosics, French Patent 706,678, 1930, Abstracted in Chemical Abstract 29(12):4168-4169, June 20, 1935.

3. Taylor, J. D., Continuous Autohydrolysis, A Key Step in the Economic Conversion of Forest and Crop Residues into Ethanol, Papers Presented at Energy From Biomass Conference, Brighton, England, Novembr 4-7, 1980.

4. Raphael Katzen Associates, Chemicals From Wood Waste, U. S. Department of Commerence, NTIS Report PB-262-489, 1975.

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8.0 PROCESS DESCRIPTION

8.1 PROCESS FLOWSHEETS AND MATERIAL BALANCE

The plant process is described schematically in the flowsheets of Drawings 24-000-100B through 24-000-109P, inclusively. Plant section designations used in the process descriptions below are those presented in the referenced drawings. The process material balance is presented in Drawing 24-000-110B, which contains the major quantitative inputs, throughputs, and outputs of the plant system.

8.2 WOOD WASTE RECEIVING, HANDLING, AND STORAGE

Raw wood waste is trucked from the forest site to the ethanol plant in semi-trailers provided with drop-sides which are unloaded by portable overhead grapple equipment. The wood waste is stacked as outside storage on concrete pad "A" as shown in the Typical Site Plan. Wood waste handled in this manner proceeds through the cleaning and shredding steps of Plant Section A to processed wood storage.

Chipped wood waste is unloaded by tractor-mounted front-end loading equipment. Such loads are relayed by portable belt transfer directly to processed wood storage (see Plant Section A).

8.3 STEAM PRETREATMENT

Wood waste proceeds from processed wood storage via inclined belt conveyor to the wood hopper bin of Plant Section B. It is delivered continuously to the steam explosion unit where it is purged with saturated steam, compressed, and exploded intermittently into the wood lint receiving drum by instrument controlled quick-release ball valve fittings.

The wood lint receiving drum is provided with baffles in the upper section to effect particulate removal, excluding fine bark fragments and wood linters from the steam recovery system for the steam explosion unit. The baffled damper drum section of the wood lint receiving system serves the dual purposes of noise diminution and steam recovery. Steam from the damper drum is delivered to the distillation section (Plant Section G) as part of the steam supply for the stripping column.

Following steam explosion treatment, the wood lint is accumulated in the bottom section of the wood lint receiving drum. With water addition and agitation, the lint is converted to a slurry to maintain a pressure seal and to allow constant delivery of a reasonably consistent feedstock for downstream processing. This slurry is removed continuously by a positive displacement pump and delivered to digester tanks (Plant Section C-1) with delivery rate controlled to match filling cycles.

8.4 WOOD WASTE DIGESTION

Delivery of wood waste slurry and sulfuric acid solution to the digester (Plant Section C-1) takes place concurrently. The sulfuric acid solution is produced by blending concentrated acid from storage with recycle water from previous batches, pumped from the digester water storage tank and the dilute sugar solution tank. The sulfuric acid concentration varies during the digestion cycle, trending toward dilution with steam addition to maintain optimum temperature and pressure. Ultimate acid concentration reached during the digestion cycle is about 0.5%

When the digester has been completely charged with wood waste slurry and sulfuric acid solution, additional water is delivered from the digester water storage tank via the digester water heater. Its temperature and steam additions during the cycle are regulated to produce digester operating conditions of about 375°F and 200 psig.

The hydrolysate steam is removed from the bottom section of the digester and proceeds through the flash drum recovery system of Plant Section C-2. The bottoms from the first stage flash drum (Section C-2) contain tars and oils resulting from resin substances in the original wood waste and various degredation products of hydrolysis and oxidation. This material is pumped to the cyclone sludge collection system of Plant Section C-1 for use as boiler fuel. The bottoms product of the second-stage flash drum is the dilute sugar solution and proceeds to storage in Plant Section E.

Overhead vapors from Section C-2, containing methanol and furfural, are condensed and routed to the flash condensate tank (Section D) for storage. Bottoms from the second stage flash drum, containing minor amounts of sugars, are pumped to the dilute sugar solution storage tank, Section E.

When hydrolysate removal has been completed, the solid residue remaining in the digester (Section C-1) contains the majority of the lignin present in the original feedstock. Pressure maintained in the digester tank is utilized to blow this residue to the cyclone in Section C-1. It proceeds through a dewatering press where its solids content is increased to approximately 65%, and through an elevator leg for storage and use as boiler fuel. Vapors recovered from the cyclone, containing methanol and furfural, are condensed and pumped to the flash condensate tank of Section D. Liquors obtained from the dewatering press are accumulated and pumped to the concentrated sugar solution tank, Section E.

8.5 CHEMICAL BYPRODUCTS RECOVERY

The flash condensate tank of Section D, containing the pooled methanol and furfural-containing condensates from wood waste digestion (Sections C-1 and C-2), serves as the distillation feedstock reservoir for chemical byproduct recovery. The condensate is pumped to the methanol recovery tower, where the combination of a reboiler, reflux system, and condenser are controlled to deliver anhydrous methanol to storage.

The second-stage liquor, containing furfural-water azeotrope, is removed as the bottoms product from the methanol recovery tower and pumped for overhead entry into the furfural recovery tower. The azeotrope is distilled and condensed, and crude furfural is pumped to storage.

8.6 NEUTRALIZATION

Fresh water is used to prepare a hydrated lime slurry for sugar solution neutralization in Section E. It enters the system by pump pressure through a vena contracta, creating sufficient suction to draw powdered hydrated lime into the water stream. The two components proceed through a two-stage static mixer system for continuous blending with the concentrated sugar solution downstream in similar static mixer equipment.

The neutralized sugar solution proceeds through a cascade sieve filter for calcium sulfate and sludge removal. It then passes through a polishing sand filter, for removal of fine particle sludges and calcium sulfate, and proceeds to storage. Solid residues from both filtration systems are removed by centrifuge and are pumped to a settling pond.

8.7 FERMENTATION

Sugar feedstock for the fermentation section (Section F) is pumped from the sugar solution storage tank of Section E. This solution is cooled and delivered to the six (6) fermentation tanks, with yeast inoculum added to the stream from the overhead yeast mixing tank prior to delivery. The solution is fermented for 36 hours with a Saccharomyces cerevisiae yeast strain, and pumped to the beer storage tank at the end of the fermentation cycle. A yeast cell cream is harvested continuously from the fermenter tanks by centrifuge, commencing at the end of each fermentation cycle. Fermenter effluents are centrifuged, with liquid fractions delivered to the beer storage tanks for subsequent distillation. The yeast cell cream passes to the yeast mixing tank to serve as inoculum for future fermentation batches.

A period of 12 hours is nominally provided for fermenter turnaround time, to allow pumping time for empty-and-fill operations and insertion of necessary cleaning cycles. The frequency of need to clean and sterilize fermenters and beer storage tanks will be determined, over a period of time and will be based on plant running history. Solutions resulting from cleaning, sterilization, and rinsing are pumped to a settling pond.

8.8 DISTILLATION

Fermentation beer exits the beer storage tanks of Section F and proceeds through the beer preheater of Section G into the top of the stripping column. The beer preheater heat exchanger transfers heat from stripping and rectifying column bottoms to the incoming beer stream, thus maximizing the steam economy of the ethanol distillation system. Steam is introduced to the stripping column only. Overhead vapors are condensed in reflux condensers between stripping and rectifying columns, thereby controlling reflux rate in the stripping column and supplying stripping steam to the rectifier sections of the distillation process.

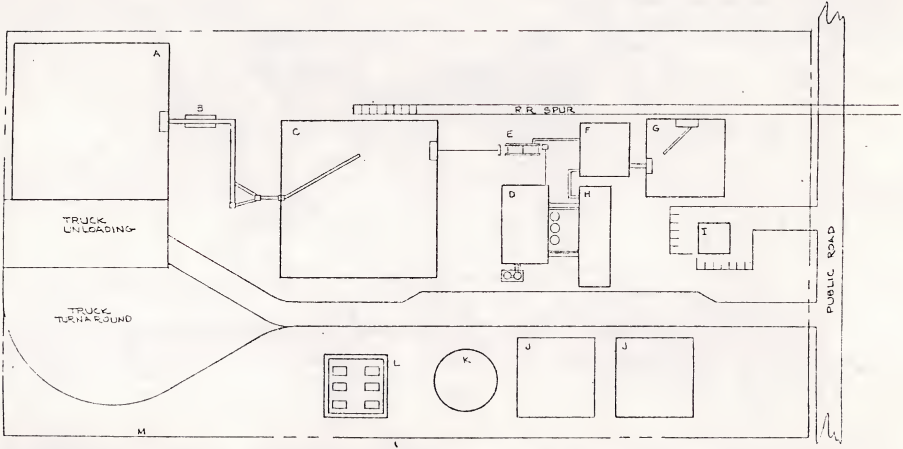
The second rectifying column delivers an alcohol vapor stream at or about the composition of the ethanol-water azeotrope, or about 190° proof ethanol. This stream is condensed by passage through the product condenser and proceeds to a pump surge tank which serves as the feedstock reservoir for azeotropic distillation.

The single azeotropic distillation column of Section G operates with pentane, hexane, or heptane as the breaker solvent or entrainer. The ethanol-water azeotropic solution enters the upper section of the azeotropic distillation column, where it is combined with incoming entrainer solvent. Under continuous distillation conditions, anhydrous ethanol (199° to 200° proof) is removed from the column bottom and pumped through a water-cooled plate cooler to product storage. Unleaded gasoline as denaturant is metered into the stream after cooling takes place. Overhead vapors from the azeotrope column contain the breaker solvent, water, and minute amounts of ethanol. These vapors are condensed and decanted to recover the breaker solvent and ethanol for recycle. Water separated in the decantation system is routed to a settling pond.

8.9 SUGAR BYPRODUCT RECOVERY

Still bottoms from the stripping column of Section G, containing pentose sugars obtained by acid hydrolysis of wood waste during digestion, are routed through the beer preheater to storage in the thin stillage tank of Section H. This tank serves as the feedstock reservoir for the sugar byproduct recovery system.

Thin stillage liquors are pumped through the two evaporation stages of Section H, which are operated in sequence with a single thermocompressor. Dehydration concentration of the liquors continues during passage through two flash drum stages. Bottoms from the flash drums are delivered to the molasses storage tank containing about 65% solids. This product meets necessary specifications for use in animal feeds or as a crude pentose sugar source for furfural manufacture. Overhead vapors from the flash drums contain minute quantities of short-chain fatty acids, furfural, ethanol, and methanol. These vapors are condensed and conveyed to a settling pond with other waste water streams for subsequent reclaim and recycle to the plant.



SCHEDULE		SIZE
A	WOOD WASTE STORAGE	200' X 200'
B	CLEANING POND	20' X 40'
C	PROCESS WOOD STORAGE	200' X 200'
D	HYDROL & NEU BLDG	100' X 60'
E	STEAM PRETREATMENT	30' X 40'
F	BOILER BLDG	56' X 70'
G	COAL STORAGE	100' X 100'
H	FERMENTATION & DISTILLATION	40' X 130'
I	ADMIN. BUILDING	40' X 40'

SCHEDULE		SIZE
J	SETTLING PONDS (2)	100' X 100' EACH
K	CLARIFIER	80' DIA.
L	TANK FARM	80' X 80'
M	LAND DIMENSIONS	1000' X 500' (11.5 Ac)

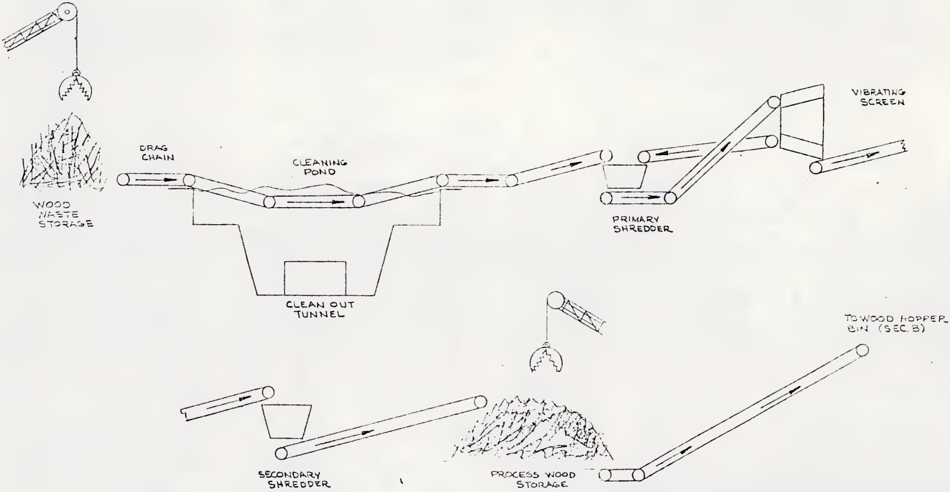
Fuel Ethanol Production From Wood Waste

SCALE: NONE
APPROVED BY JHW
DRAWN BY MAS
DATE 11/81
REVISED

TYPICAL SITE PLAN

MULTITECH INC BUTTE MT
DRAWING NUMBER 24-000-100-B

FIGURE 8-1.--Typical Site Plan



Fuel Ethanol Production From Wood Waste		
SCALE. NONE DATE. 11/81	APPROVED BY JHW	DRAWN BY MAS REVISED
SECTION 'A' WOOD HANDLING & STORAGE		
MULTITECH INC BUTTE MT		DRAWING NUMBER 24-000-101-B

FIGURE 8-2.--Section "A" Wood Handling and Storage

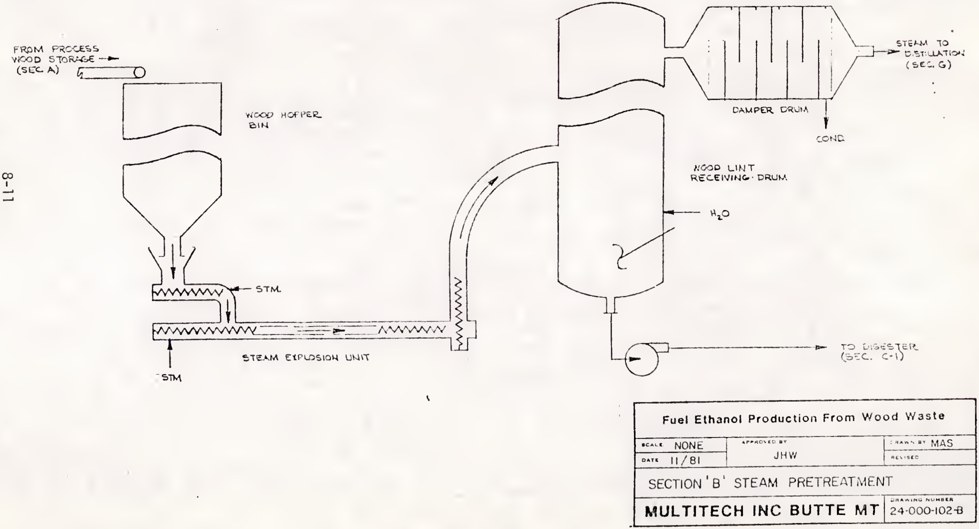
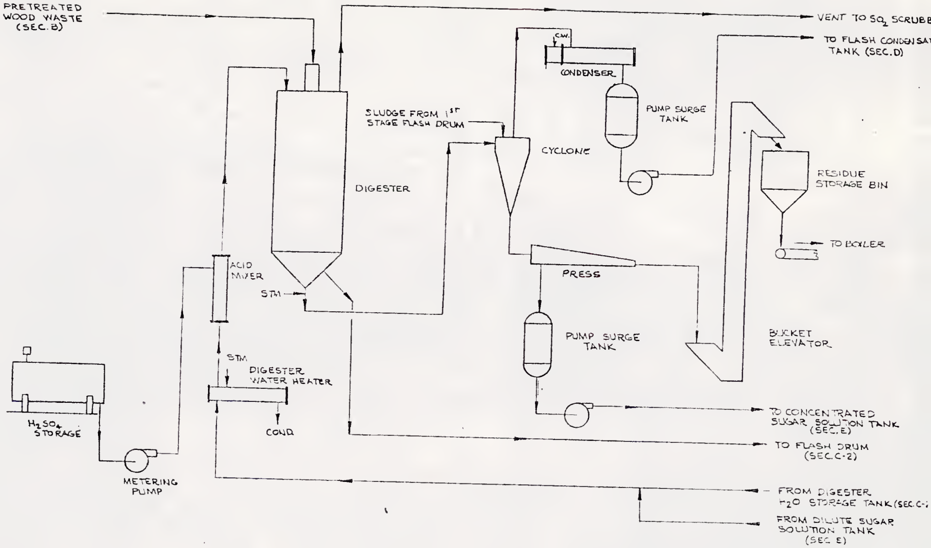


FIGURE 8-3.--Section "B" Steam Pretreatment



Fuel Ethanol Production From Wood Waste		
SCALE NONE DATE 11/81	APPROVED BY JHW	DRAWN BY MAS REVISED
SECTION 'C-1'- DIGESTION		
MULTITECH INC BUTTE MT		DRAWING NUMBER 24-000-103-B

FIGURE 8-4.--Section "C-1" Digestion

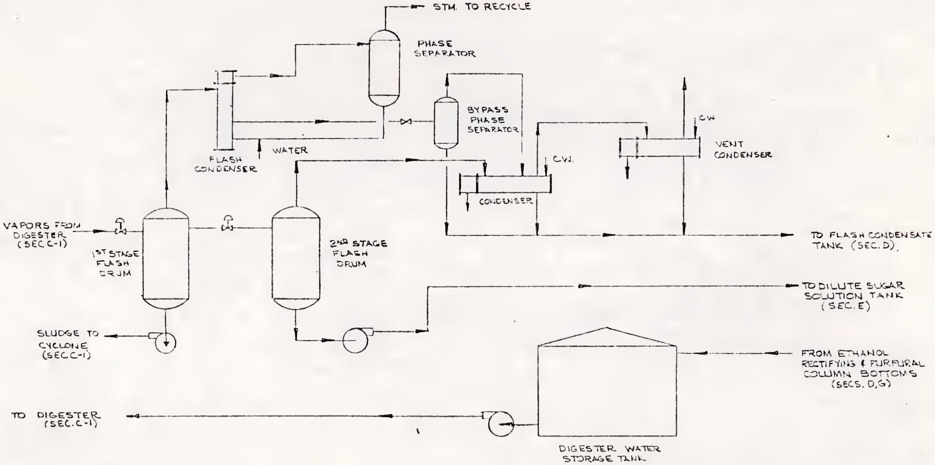

STM. TO RECYCLE
PHASE SEPARATOR
BYPASS PHASE SEPARATOR
C.W.
VENT CONDENSER
FLASH CONDENSER
WATER
C.W.
CONDENSER
VAPORS FROM DIGESTER (SEC.C-1)
1ST STAGE FLASH DRUM
2ND STAGE FLASH DRUM
TO FLASH CONDENSATE TANK (SEC. D)
TO DILUTE SUGAR SOLUTION TANK (SEC. E)
SLUDGE TO CYCLONE (SEC.C-1)
FROM ETHANOL RECTIFYING & FURFURAL COLUMN BOTTOMS (SECS. D,G)
TO DIGESTER (SEC.C-1)
DIGESTER WATER STORAGE TANK

FIGURE 8-5.--Section "C-2" Digestion

Fuel Ethanol Production From Wood Waste

SCALE NONE	APPROVED BY JHW	DRAWN BY MAS
DATE 11/81		REVISED

SECTION 'C-2' - DIGESTION

MULTITECH INC BUTTE MT DRAWING NUMBER 24-000-104-B

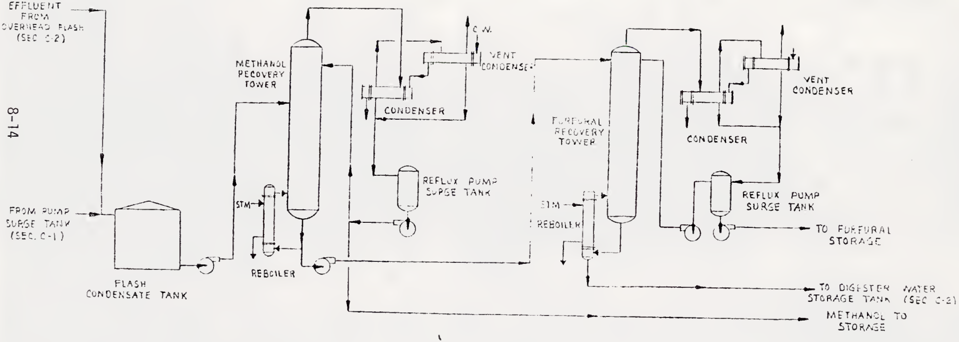


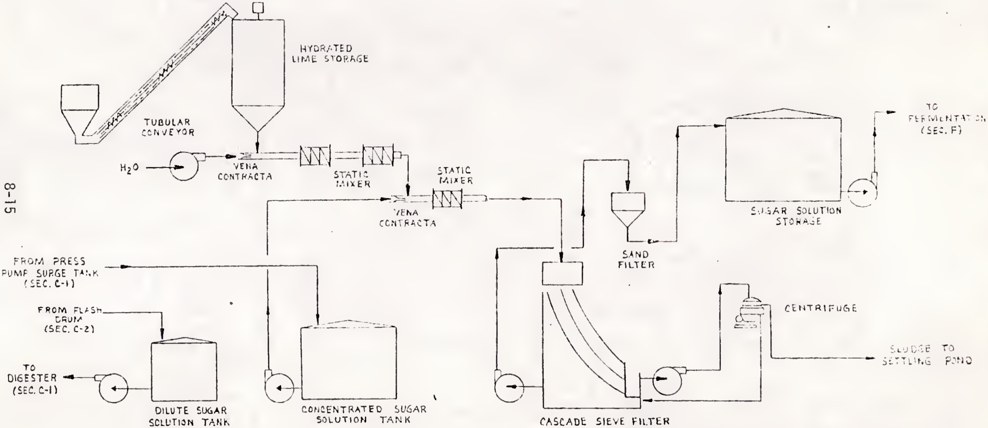
FIGURE 8-6.--Section "D" Chemical Byproducts

Fuel Ethanol Production From Wood Waste

SCALE: NONE	APPROVED BY	DRAWN BY MAS
DATE 11/81	JW	REVISED

SECTION 'D' - CHEMICAL BYPRODUCTS

MULTITECH INC BUTTE MT DRAWING NUMBER 24-000-105-B



Fuel Ethanol Production From Wood Waste

SCALE NONE
APPROVED BY JW
DRAWN BY MAS
DATE 11/81
REVISED
SECTION 'E' - NEUTRALIZATION
MULTITECH INC BUTTE MT
DRAWING NUMBER 24-000-106-B

FIGURE 8-7.--Section "E" Neutralization

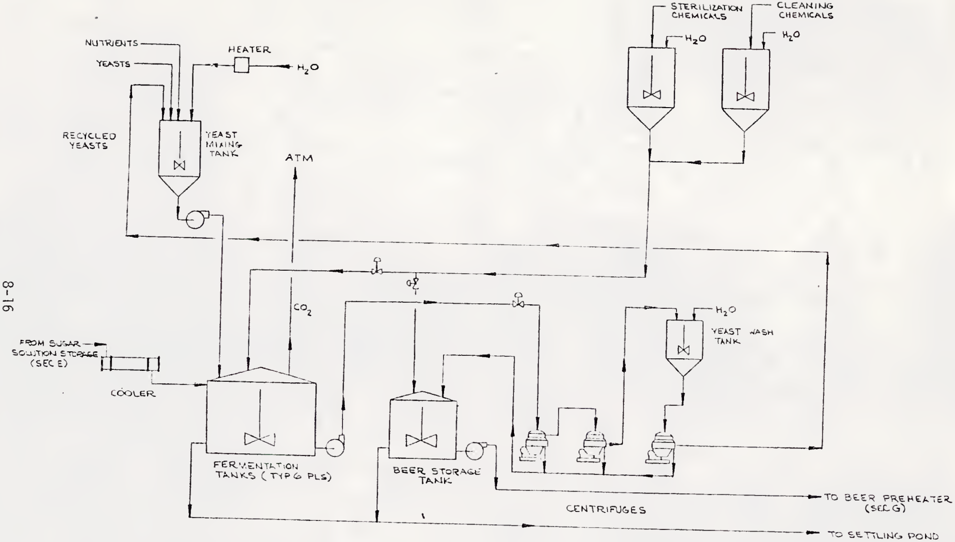


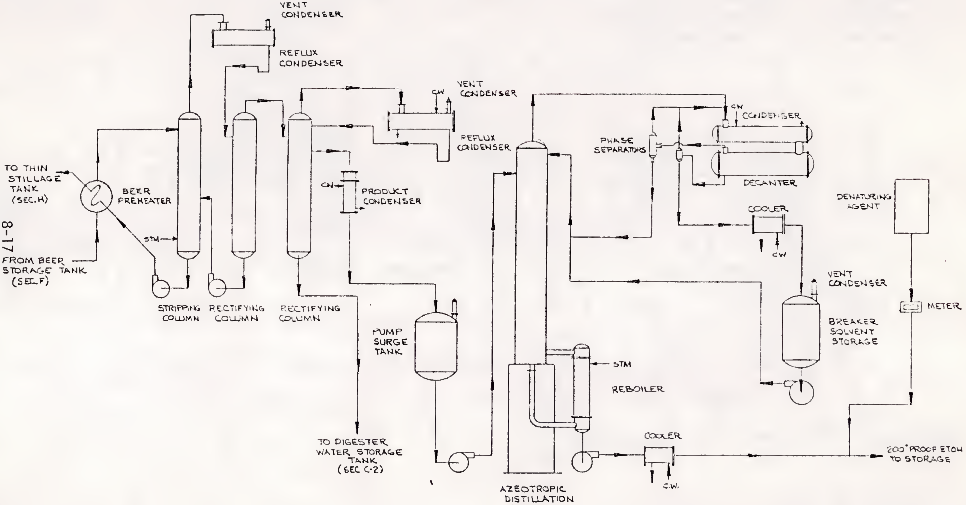
FIGURE 8-8.--Section "F" Fermentation

Fuel Ethanol Production From Wood Waste

SCALE NONE	APPROVED BY JW	DRAWN BY MAS
DATE 11/81		REVISED

SECTION 'F' - FERMENTATION

MULTITECH INC BUTTE MT DRAWING NUMBER 24-000-107-B



Fuel Ethanol Production From Wood Waste

SCALE NONE
DATE 11/81
APPROVED BY JW
DRAWN BY MAS
REVISED

SECTION 'G' - DISTILLATION

MULTITECH INC BUTTE MT
DRAWING NUMBER 24-000108-B

FIGURE 8-.9--Section "G" Distillation

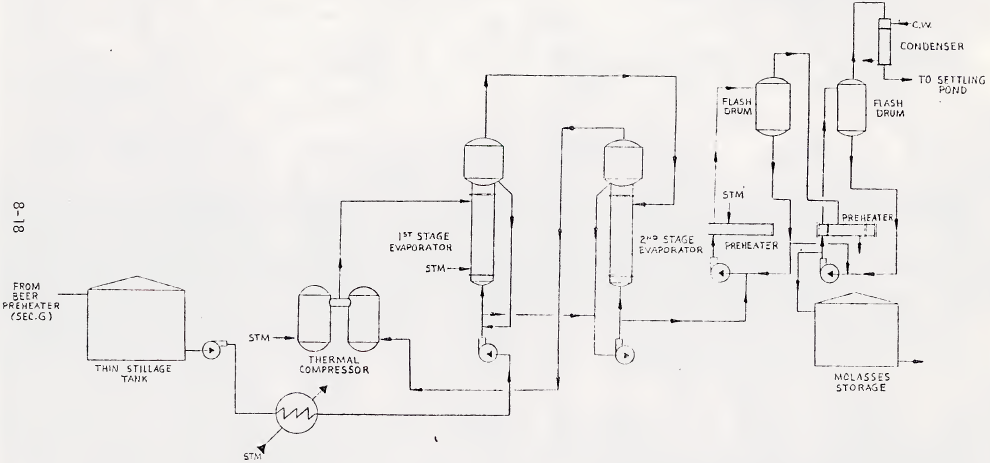
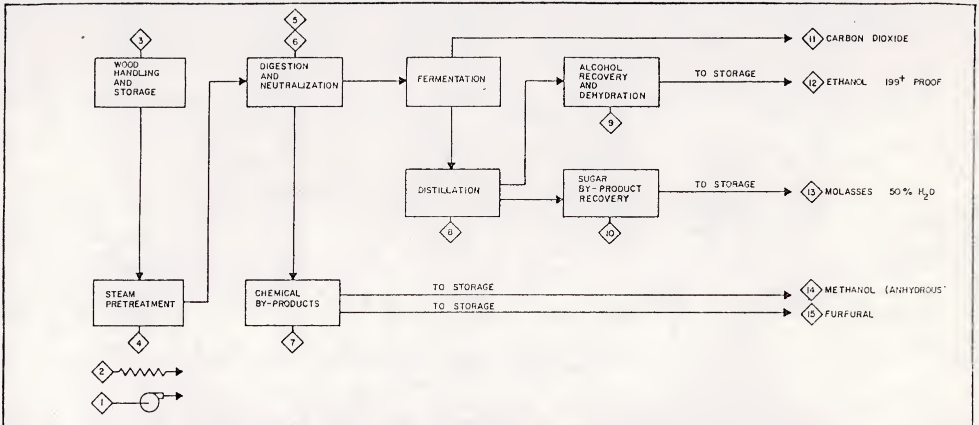


FIGURE 8-10.--Section "H" Sugar Byproduct Recovery

Fuel Ethanol Production From Wood Waste		
SCALE NONE	APPROVED BY JW	DRAWN BY MAS
DATE 11/81		REVISED
SECTION 'H' SUGAR BYPRODUCT RECOVERY		
MULTITECH INC BUTTE MT		DRAWING NUMBER 24-000-109-B



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
FURFURAL LBS/DAY															3000		
METHANOL GAL/DAY														364			
MOLASSES LBS/DAY													24,000				
ETHANOL GAL/DAY												7,600					
CARBON DIOXIDE LBS/DAY											49,100						
STEAM LBS/DAY				380,000			35,000	167,200	76,000	96,000							
HYDRATED LIME LBS/DAY						9530											
SULFURIC ACID LBS/DAY					16,800												
WOOD INTAKE ODT/DAY			155														
ELECTRICAL KWH/DAY		54,528															
WATER MILL. GAL/DAY	0.5																
STM. RCV & RECYCLE LBS/DAY				(323,000)			(31,500)	(150,400)	(68,400)	(86,400)							

FLOW DIAGRAM AND MATERIAL BALANCE

Fuel Ethanol Production From Wood Waste

SCALE: NONE
DATE: 11/81
APPROVED BY JHW
DRAWN BY MAS
REVISED

2.5 MILLION GPY PLANT

MULTITECH INC BUTTE MT
DRAWING NUMBER 24-000-110-B

FIGURE 8-11.--2.5 Million GPY Plant

9.0 PLANT AND EQUIPMENT COSTS

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FUEL ETHANOL PRODUCTION FROM WOOD WASTE
PLANT CAPITAL ESTIMATE SUMMARY

ACCOUNT	DESCRIPTION	SECTION	MATERIALS	LABOR	SUBCONTRACT
100-0	Equipment				
	Wood Handling and Storage	A	$ 303,642	$ 59,295	
	Steam Pretreatment	B			$1,800,000
	Digestion	C	707,052	40,236	26,000
	Chemical By-Products	D	236,922	16,200	
	Neutralization	E	423,329	24,210	
	Fermentation	F	667,361	64,920	
	Distillation	G	618,516	34,620	
	Sugar By-Product Recovery	H	509,944	18,000	
1-0	Land, Buildings	I			1,358,100
2-0	Site Improvements	I			108,258
3-0	Concrete Pads	I			378,455
5-0	Miscellaneous Structural Steel	I			48,980
15-0	Mechanical	I			989,333
16-0	Electrical	I			156,201
100-0	Boilers/Coal Handling	I	1,232,701	23,359	
	SUBTOTAL		4,699,467	280,840	4,865,327
	10% Profit and Administration		469,947	28,084	486,533
	Labor Indirect @ 45%			126,378	
	Freight (1,758,000 lb) @ 12.50 cwt		219,750		
	ELEMENT SUBTOTAL		5,389,164	435,302	5,351,860
	Plant Design @ 6% Total				670,580
	ELEMENT SUBTOTAL		5,389,164	435,302	6,022,440
	PLANT TOTAL		11,846,906		

ESTIMATE SUMMARY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Wood Handling, Storage and Reclaim Section A

ESTIMATE NO

SHEET NO. S-1

PREPARED BY: J. Richards DATE 10/81

CHECKED BY. DATE.

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Cleaning Pond	1 each	11,100	11,100	75	75	143	10,725			
	Primary Shredder	1 each	58,500	58,500	158	158	30	4,740			
	Secondary Shredder	1 each	36,355	36,355	86	86	30	2,580			
	Vibrating Screen	1 each	11,518	11,518	34	34	30	1,020			
	Drag to 1" Hog Conveyor	1 each	26,669	26,669	249	249	30	7,470			
	Screen to Storage Conveyor	1 each	26,669	26,669	249	249	30	7,470			
	Storage to Digester Conveyor	1 each	26,669	26,669	249	249	30	7,470			
	1^{0} Hog to Screen Conveyor	1 each	12,859	12,859	118	118	30	3,540			
	Screen to 2^{0} Hog Conveyor	1 each	12,859	12,859	118	118	30	3,540			
	Screen to 1" Hog Conveyor	1 each	12,859	12,859	118	118	30	3,540			
	Drag Chain	1 each	67,585	67,585	240	240	30	7,200			
	Subtotal			303,642				59,295			
	Freight	115,000 lb									

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Steam Pre-Treatment Section B

ESTIMATE NO

SHEET NO. S-2

PREPARED BY: J. Richards DATE 10/81

CHECKED BY. DATE.

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Steam Pre-Treatment										
	Vendor Quote	2 each							900,000	1,800,000	
	Subtotal									1,800,000	
	Total Freight Weight	(included)									

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Digestion Section C

ESTIMATE NO.
SHEET NO. S-3
PREPARED BY: J. Richards DATE: 10/81
CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Digesters	4 each		397,953	60	240	30	7,200			
	Tanks	9 each		33,396	40	360	30	10,800			
	Digester Water Heater	1 each		21,203	24	24	30	720			
	Condenser	1 each		17,300	18	18	30	540			
	Condenser with Vent Cond.	1 each		18,520	20	20	30	600			
	Flash Condenser	1 each		40,310	32	32	30	960			
	Storage Tanks	3 each		42,506		126	30	3,780			
	Pumps	7 each		14,813		162	18	2,916			
	Bucket Conveyor	1 each		15,169	80	80	30	2,400			
	SO_2 Scrubber	1 each		4,710	8	8	30	240			
	Hogged Fuel Storage Bin	1 each								26,000	
	Cyclones	2 each		12,576	40	80	30	2,400			
	Acid Dilution Mixer/Feeder	1 each		5,596	16	16	30	480			
	Dewatering Press	1 each		83,000		240	30	7,200			
	Subtotal			707,052				40,236		26,000	
	Total Freight Weight	263,000 lb									

ESTIMATE SUMMARY

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Chemical By-Product Processing Section D

ESTIMATE NO.
SHEET NO. S-4
PREPARED BY J. Richards DATE: 10/81
CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Methanol Column	1 each		$43,683	40	+2,010	30	3,210			
	Furfural Column	1 each		43,683	40	+2,010	30	3,210			
	Overhead Condenser	1 each		11,400	12	12	30	360			
	Overhead Condenser	1 each		18,450	18	18	30	540			
	Vent Condeners	2 each	$ 5,290	10,580	12	24	30	720			
	Reboilers	2 each	21,203	42,406	24	48	30	1,440			
	Pump Surge Tanks	2 each	4,356	8,712	40	80	30	2,400			
	Pumps	4 each	2,001	8,004	22	88	30	2,640			
	Me OH Storage Tank	1 each		22,950	26	26	30	780			
	Furfural Storage Tank	1 each		27,054	30	30	30	900			
	Subtotal			236,922				16,200			
	Total Freight Weight	65,000 lbs									

MULTITECH

ESTIMATE SUMMARY

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Neutralization Section E

ESTIMATE NO

SHEET NO. S-5

PREPARED BY J. Richards DATE 10/81

CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Concentrated Sugar Soln. Tank	1 each		$ 71,602	80	80	30	$ 2,400			
	Dilute Sugar Soln. Tank	1 each		31,208	48	48	30	1,440			
	Sugar Soln. Tank	1 each		71,602	80	80	30	2,400			
	Pumps	6 each		22,438		144	30	4,320			
	Cascade and Sand Filter	1 each		130,000		240	30	7,200			
	Centrifugal Separator	1 each		90,000	80	80	30	2,400			
	Lime Storage Bin	1 each		779				450			
	In-line Mixers	2 each		3,000		80	30	2,400			
	Tubular Conveyor & Hopper	1 each		2,700		40	30	1,200			
	Subtotal			423,329				24,210			
	Total Freight Weight	180,000 lbs.									

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Fermentation Section F

ESTIMATE NO
SHEET NO. S-6
PREPARED BY: J. Richards DATE 10/81
CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Pumps	8 each		$ 27,416		240	$30	$ 7,200			
	Fermentation Tanks	6 each	27,281	163,686	80	480	30	14,400			
	Beer Storage Tanks	2 each	27,281	54,562	80	160	30	4,800			
	Small Tanks	4 each	14,471	57,884	40	160	30	4,800			
	Agitators	12 each	5,600	67,200	32	384	30	11,520			
	Sugar Soln. Cooler	1 each		26,613	20	20	30	600			
	Centrifugal Separators	3 each	90,000	270,000	240	720	30	21,600			
	Subtotal			667,361				64,920			
	Total Freight Weight	490,000 lbs.									

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Distillation Section G

ESTIMATE NO.

SHEET NO. S-7

PREPARED BY: J. Richards DATE 10/81

CHECKED BY: DATE

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Equipment Subtotal (Vendor Quote)	All	$545,000	545,000	1,000	1,000	$ 30	$30,000			
	Ethanol Storage Tanks	2 each	34,384	68,768	65	130	30	3,900			
	Ethanol Transfer Pump	1 each	4,748	4,748	24	24	30	720			
	Subtotal			618,516				34,620			
	Total Freight Weight	212,000 lbs.									

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Sugar By-Product Recovery Section H

ESTIMATE NO.

SHEET NO. S-8

PREPARED BY: J. Richards DATE 10/81

CHECKED BY DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Pumps with Drivers	6 each		$ 25,886		152	$30	$ 4,560			
	Evaporator/Steam Compressor	2 each		246,041		160	30	4,800			
	Condensor	1 each	$16,300	16,300		18	30	540			
	Flash Drums	2 each	4,356	8,712	40	80	30	2,400			
	Thin Stillage Tank	1 each		52,015	30	30	30	900			
	Concentrated Solution Tank	1 each		97,375	88	88	30	2,640			
	Pre-heater	3 each	21,205	63,615	24	72	30	2,160			
	Subtotal			509,944				18,000			
	Total Freight Weight	173,000 lbs.									

ESTIMATE SUMMARY

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

General Accounts Section I

ESTIMATE NO.

SHEET NO. S-9

PREPARED BY: J. Richards DATE: 10/81

CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
1-0	Land								$103,500		
	Buildings								753,600		
	Loaders								501,000		
	Subtotal									$1,358,100	
2-0	Earth Work								44,352		
	Water Distribution								20,826		
	Asphalt								17,520		
	Settling Ponds								25,560		
	Subtotal									108,258	
3-0	Concrete Pads								378,455		
	Subtotal									378,455	
5-0	Misc. Structural Steel								48,980		
	Subtotal									48,980	
15-0	Sewage and Drainage								16,185		
	Process Piping								814,720		
	Instrumentation & Control								150,762		
	Pipe Hangers & Supports								7,666		
	Subtotal									989,333	
16-0	Power Distribution								130,361		
	Instrumentation Wiring								25,840		
	Subtotal									156,201	

ESTIMATE SUMMARY

MULTITECH

PROJECT: FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment — General Accounts
Boilers, Coal Handling — Section I

ESTIMATE NO
SHEET NO. S-10
PREPARED BY: J. Richards DATE 10/81
CHECKED BY: DATE:

MAIN ACCOUNT	DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
			UNIT PRICE	AMOUNT	UNIT	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
100-0	Boilers	5 each	240,000	$1,200,000	80	400	$ 30	$ 12,000			
	R. R. Unloading Hopper	1 each	1,352	1,352				836			
	Swing Belt Conveyors	2 each	12,859	25,718	118	236	30	7,080			
	Stoker Bin Feeders	1 each	5,631	5,631				3,443			
	Subtotal			1,232,701				23,359			
	Freight	260,000 lbs.									

QUANTITY SURVEY

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION A

ACCOUNT 100-0 Equipment

Wood Handling, Storage and Reclaim

ESTIMATE NO

SHEET NO A-1 of 5

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	WIDTH	LENGTH	HEIGHT/ DEPTH	CAPACITY	SPEED	DRIVE H. P.		
3-0	Cleaning Pond	1 each	40'	20'	10'	60,000 gal.				
100-1	Drag Chain	1 each		70'		40T/Hr				
100-1	Conveyors	7 each								
	Drag to Primary Hog		30"	100'	10'	40T/Hr	100 FPM	5		
	Primary Hog to Screen			30'		40T/Hr	100 FPM			
	Screen to Secondary Hog			30'	5'	40T/Hr	100 FPM			
	Screen to 1^0 Hog			30'		40T/Hr	100 FPM			
	2^0 Hog to Storage		30"	100'	45'	40T/Hr	100 FPM	5		
	Storage to Digester	2 each	30"	100'	45'	40T/Hr	100 FPM	5		
N/A	Storage Area	2 each	200'	200'	Covered in Account 3-0					
N/A	Bulldozer			Covered in Account 1-0						
100-391	Primary Shredder	1 each				40T/Hr		400		
100-391	Secondary Shredder	1 each				20T/Hr		200		
100-65	Screen Shaker	1 each	3'	12'		40T/Hr				

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Wood Handling, Storage, and Reclaim - Cleaning Pond, Shredders, Screen Separator

ESTIMATE NO
SHEET NO. A-2 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
3-0	Cleaning Pond	1 ea.					
3-10	Gang formed concrete walls 12" thick heavily reinforced	75 cy	$ 148	$ 11,100			
	Installation - Labor	75 cy	143	10,725			
100-391	Primary Shredder - SH4454 40 ton, 900 RPM, 40 TPH	1 ea.	50,300	50,300	19,000	19,000	96 MH Installation
	400 HP - NEMA A, Class F, TEFC Block 5	1 ea.	8,200	8,200			62 MH
	Total Primary Shredder			58,500		19,000	
	Installation - Labor	158 MH	$30/hr	4,740			
100-391	Secondary Shredder - SH3640 1,200 RPM, 20 TPH	1 ea.	30,600	30,600		10,000	48 MH
	200 HP - NEMA A, Class B, TEFC Block 5	1 ea.		5,755			38 MH
	Total Secondary Shredder			36,355		10,000	
	Installation - Labor	86 MH	$30/hr	2,580			
100-65	Vibrating Screen V-700 3 x 12	1 ea.	10,900	10,900	3,600	3,600	28 MH
	5 HP - NEMA A, Class B, TEFC Explosion Proof, Block 6	1 ea.	618	618			6 MH
	Total Vibrating Screen			11,518			
	Installation - Labor	34 MH	$30/hr	1,020			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Wood Handling Storage and Reclaim - Conveyors

ESTIMATE NO
SHEET NO. A-3 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-1	Conveyors, 30' Horizontal, 8^0 Rise 5' Vertical Dist.	3 each					
	Belt = 2 ply, RMA 105 x 30", 83 fpm	65 each	$ 20.7	$ 1,346	4.5	293	4 MH Installation
	Mechanical Splice Kit	2 each	89	178			8 MH Installation
	Head Pulley, Drive & Drive	1 each		3,215		850	6 MH Installation
	Tail Pulley (Gravity Take-up)	1 each		720		650	2 MH Installation
	Snub and Bend Pulleys	1 each		465		140	2 MH Installation
	Trough Pulleys	8 each	185	1,480	62	496	32 MH Installation
	Return Idlers	3 each	85	255	33	99	12 MH Installation
	2' - 0 Truss	30 feet	38	1,140	35	1,050	9 MH Installation
	A-Frame Supports	2 each	500	1,000	395	790	6 MH Installation
	Conveyor	3 each	415	1,245	468	1,404	9 MH Installation
	Loading Hopper	1 each		230		250	2 MH Installation
	Discharge Hood	1 each		485		550	4 MH Installation
	3 H.P. Nema, TEFC, Class B, Block 5			1,100		400	22 MH Installation
	Total Conveyor	1 each		12,859		6,972	
	Installation Labor	118 m.h.	30	3,540			
	Total 30' Conveyors	3 each	12,859	38,577	6,972	20,916	
	Installation Labor	3 each	3,540	10,620			

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Wood Handling, Storage, and Reclaim - Conveyors

ESTIMATE NO
SHEET NO A-4 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-1	Conveyors, 100' Horizontal Dist. 25^0 Rise = 42' Vertical Dist.	3 each					
	Belt = 2 ply R.M.A. 105 x 30"w	220 feet	$20.70	$ 4,554	4.5	990	5 MH Installation
	Mechanical Splice Kit	2 each	89	178			8 MH Installation
	5 h.p. Head Pulley, Drive and Drive Guard	1 each		3,215		850	6 MH Installation
	Tail Pulley (Gravity Take-up)	1 each		720		650	4 MH Installation
	Snub and Bend Pulleys	1 each		465		140	2 MH Installation
	Trough Pulleys	22 each	185	4,070	62	1,364	88 MH Installation
	Return Idlers	10 each	85	850	33	330	40 MH Installation
	2'-0" Truss	100 feet	38	3,800	35	3,500	30
	A-Frame Supports	2 each		2,400		2,428	6
	Conveyor Frame	10 each	415	4,150	468	4,680	30
	Loading Hopper	1 each		230		250	2
	Discharge Hood	1 each		485		550	4
	5 HP Memo A, TEFC Class B	1 each		1,512		500	24 MH Installation
	Total Conveyor	1 each		26,669		16,232	
	Installation Labor	249 m.h.	30	7,470			
	Total 100' Conveyors	3 each	26,669	80,007	16,232	48,696	
	Installation Labor	3 each	7,470	22,410			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Wood Handling, Storage, and Reclaim - Conveyors

ESTIMATE NO
SHEET NO. A-5 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-1, 2	Drag Chain - Joy Mfg. Co.	1 each					
	45 pounds/ft^3						
	Drive and Chain Guard	1 each	$10,910	$10,910		750	
	Head and Tail Shaft	2 each		2,215		600	
	Chain, 6670 pound maximum load	150 ft	14	16,650	15	2,250	X 3 spaced 844 chain
	Idler Pulleys	14	1,380	19,320	250	3,500	X 3 self adjusting pulleys, 42"
	Conveyor Frames	70 ft	225	15,570	70	4,900	
	25 HP Motor Class B, FEFC, NEMA Block 6	1 each		2,740		500	
	Total Drag Chain	1 each		67,585		12,500	
	Installation Labor	240 hrs	30	7,200			

QUANTITY SURVEY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION B
ESTIMATE NO
ACCOUNT
100-0 Equipment
Steam Pretreatment
SHEET NO B-1 of 2
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	RAW #/HR	STEAM #/HR	DIA.	T to T	CAP.			
100-0	Steam Pretreatment	2	14,000	7,826	30"	25'	5 tons			
	Stake Technologies with									
	Storage Bin and Conveyors									

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Steam Pretreatment - Section B

ESTIMATE NO
SHEET NO. B-2 of 2
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-0	Steam Pretreatment	2	$900,000	$1,800,000	N/A		Total installed cost, freight, and labor included
	30' diameter x 25' long with hopper, feeders, and collection bins						Subcontract unit price

QUANTITY SURVEY

PROJECT	FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION C
ACCOUNT	
	100-0 Equipment
	Digestion Section
ESTIMATE NO	
SHEET NO	C-1 of 13
PREPARED BY	J. Richards
DATE	10/81
CHECKED BY	
DATE	

ACCOUNT	DESCRIPTION	QUANTITY	DIA	T to T	PRESSURE RATING	TEMP.	MATL.	MATL. THICKNESS	CAP./AREA	MATL. RATING
100-341	Digester	4 ea.	96"	20'-0"	250 psig	400°F	Alloy 825	3/4"		
100-341	Small Tanks (water level, pump surge, 1st stage flash drum, 2nd stage flash)	7 ea.	24"	4'-0"	75 psig	400°F	316 SS	1/2"		
100-341	Small Tanks (bypass phase separator, phase separator)	2 ea.	24"	4'-0"	75 psig	350°F	C.S.	1/2"		
100-220	Digester Water Heater	1 ea.	16"		790 psig	550°F	Alloy 20 C.S.		400 ft²	600 #
100-230	Condenser	1 ea.			75 psig	100°F	Alloy 20 C.S.		190 ft²	150 #
100-220	Condenser	1 ea.	14"		20 psig	400°F	Alloy 20		320 ft²	150 #
100-230	With Vent Condenser	1 ea.					C.S.		20 ft²	150 #
100-220	Flash Condenser	1 ea.	28"		225 psig	400°F	Alloy 20 C.S.		1,220 ft²	300 #
100-341	H2SO4 Storage Tank	1 ea.	72"	12'-0"			C.S.	5/8"	9,600 gal	
100-341	Digester Water Storage Tank	1 ea.	78"	20'-0"			C.S.	5/8"	20,000 gal	
100-341	Flash Tank	1 ea.	66"	15'-0"			C.S.	5/8'	10,000 gal	
100-280	Pumps		FLOW	HEAD		MATL	DISP.	DRIVER		
	Acid Supply	1 ea.	5 gpm	10		C.S.	Metering	1.5 HP		
	Xfer to Dilute Storage	1 ea.	10 gpm	30		316 SS	In line	1.5 HP		
	Condensate Transfer	1 ea.	10 gpm	25		316 SS	In line	1.5 HP		
	Sludge Transfer	1 ea.	10 gpm	70		316 SS	Sewage	5.0 HP		
	Sugar Solution Transfer	1 ea.	10 gpm	30		316 SS	In line	1.5 HP		
	Digester Water	1 ea.	300 gpm	102		316 SS	In line	15.0 HP		
	Tower Feed	1 ea.	50 gpm	30		316 SS	Centr.	1.5 HP		
			DENSITY	HEIGHT	TYPE	MATL.	RATE	DRIVE		
100-2	Bucket Elevator	1 ea.	30#/ft³	30 ft	Cont. Belt	C.S.	20 T/hr	3 HP		
100-115	SO2 Scrubber	1 ea.								
	Residue Storage Bin with Feeder	1 ea								

QUANTITY SURVEY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
ACCOUNT
100-0 Equipment
Digestion

ESTIMATE NO
SHEET NO C-2 of 13
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	T to T	MATL.	THICK.	CAPAC.	HP	FLOW	
100-0	Residue Cyclone									
	2' diameter x 4' drum 316 SS	2 ea.	24"	4'	316 SS	1/2"				
	From Page A-2									
	Acid Dilution Mixer				304 SS		500 gal		20.8 gph	
	Dewatering Press						2 ton/hr			

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Digestion

ESTIMATE NO
SHEET NO C-3 of 13
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Digesters	4 ea					
100-342 pg. 8	Shell Alloy 825 100% X-rayed 3/4" thick material, no stress relief	80 ft	$ 1,484	$118,720	775.1#	62,008 #	4 times A-285 C.S. prices
100-342 pg. 8	Semi Eliptical Heads 2 for each Alloy 825, 100% X-rayed 3/4" thick material	4 sets	20,064	80,256	5,496	21,484	4 times A-285 C.S. prices
100-344	Angle Legs for Vertical Vessels,	16 ea.	92	1,472	80#	1,280#	6" x 6" 1/2" C.S. 4' long
pg. 1	Base plates for legs	16 ea.			20.5#	328	8-1/2" x 8-1/2" x 1" C.S.
100-347	Buttweld Flange Type Nozzles						All flanges 600# R. F.
	2" 2 per hydrolyzer 600#	8 ea.	146	1,168	17	136	Buttweld, 4 times
	4" 2 per hydrolyzer 600#	8 ea.	271	2,168	59	472	A-105 prices
	18" 1 per hydrolyzer 600#	4 ea.	7,144	28,576	763	3,052	
100-356	Ladder Support Clips	80 ft	32.56	2,605			
5-11	Platforms Ladders and Handrails						
	Uncaged ladder	40 ft	14.0	560	10	400	
	Caged Ladder	280 ft	25.20	7,056	18	5,040	
	Circular Platform 3/16" x 1"	76 ft	140.00	10,640	100	7,600	
	Handrails	76 ft	28.00	2,128	20	1,520	
100-0	Miscellaneous (lifting lugs, trays if applicable)	4 ea	35,651	142,604	11,545	46,180	
100-0	Digester Total	4 ea	99488.25	397,953	37,500	150,000	
	Installation Labor	4 ea	60 hrs	240 hrs	30	$ 7,200	Composite crew rate and crane time based on 19 tons weight for each unit.

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Small Tanks

ESTIMATE NO

SHEET NO C-4 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-341	Small Tanks Stainless Steel 316	7 ea					Stainless Steel 316
	Small Tanks Carbon Steel A-285	2 each					price 3 times C.S.
							A-285
100-342	C.S. Shell x 3, 316 SS, 100% X-rayed	4'	303	1,212	130.97	524	Price for supports
	1/2" material, 24" diameter						equals 2 times
100-342	C.S. S. E. Heads x 3 316 SS	Pair	966	966	143.	143	
	100% X-rayed, 1/2" material						
	Miscellaneous (support equipment, etc.)	AR		2,178	6	667	
	Total One Tank			4,356		1,334	
	Total S.S. Small Tank	7 ea.	4,356	30,492	1,334	9,338	
100-342	C.S. A-285 Shell, 100% X-rayed	4	101	404	131	524	
pg. 2	1/2" material 24 " diameter						
100-342	C.S. S. E. Heads 100% X-rayed,	Pair	322	322	143	143	
	1/2" material						
	Miscellaneous	AR	726	726	667	667	
	Total One Tank			1,452		1,334	
	Total C. S. Small Tanks		1,452	2,904	1,334	2,668	
	Total Small Tanks	9 ea.		33,396		12,006	
	Installation Labor	9 ea.	40 hrs	360 hrs	$30.00	$10,800	Composite crew and crane
							time based on 40 hours
							total time each drum

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Water Heater

ESTIMATE NO

SHEET NO. C-5 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-220	Digester Water Heater	1 ea.					
	TEMA R Shell and Tube Heat Exchanger	400 ft^2			14#/ft^2	5,600	
	Type BEU, 600 # rating						
100-220	16" Exchanger Shell Diameter	1 ea.	$ 4,676	$ 4,676			
pg. 2	Base Price, Carbon Steel						
pgs. 3-4	Front and Rear Heads	2 ea.	N/C	N/C			
pg. 6	16" Shell, 10' Bundle Length	10 ft	128	1,280			
pg. 7	4" Nozzle ANSI 600#	1 ea.	251	251			
	1-1/2" Coupling 600#	1 ea.	45	45			
pg. 8	U-Tubes, Alloy 20, 3/4" Size	90 ea.	$6.94	625			4/3 times 316 SS
	No. of Tubes						
	Heating Surface Area	400 ft^2	22.40	8,960			
pg. 9	Support Saddles and Lifting Lugs	4 ea.	172	688			
	Longitudinal Baffles	400 ft^2	11.07	4,428			
	ASME Code Stamp and Data Sheets			250			
	Total Digester Water Heater	1 ea.		$21,203		5,600	
	Installation Labor	24 hrs	$30/hr	720			Based on tonnage, crew and crane

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Residue Flash Condenser

ESTIMATE NO

SHEET NO. C-6 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-230	Condenser						
	Model 85-E, Stokes Inc. Vertical tube surface condenser and receiver, vacuum type	1 ea	$12,300	$12,300		1,850	
	Modify using Alloy 20 tubes			5,000			
	Total - Condenser			17,300		1,850	
	Installation labor	18 mh	$30/hr	540			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Second Stage Flash Condenser

ESTIMATE NO

SHEET NO. C-7 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-220	Condenser	1 ea. 320 ft^2			10	3,200	
	with vent condenser	20 ft^2		$ 2,470		700	
	Alloy 20 tubes, carbon steel shell 150# rating						
100-220 pg 2	Basic shell 14" diameter carbon steel	1 ea.	$ 3,210	3,210			
	Front and rear heads	2 ea.		N/C			
	Shell 14", 10' bundle length	10 ft.	87	870			
	2" Nozzle	1 ea.	91	91			
	1" Coupling	1 ea	24	24			
	U-Tubes, Alloy 20, 3/4" size	100 tubes	5.94	594			
	Cooling Area Alloy 20	320 ft.	22.40	7,168			
	Support Saddles & Lifting Lugs	2 ea.	150	300			
	Longitudinal Baffles	320 ft	11.07	3,543			
	ASME Code Stamp			250			
	Total Condenser			$18,520		3,900	
	Installation - Labor	20 mh	$30/hr	600			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - First Stage Flash Condenser

ESTIMATE NO

SHEET NO. C-8 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-220	Flash Condenser	1 ea.					
	300#, Alloy 20 tubes C. S. shell	1,220 ft^2			9	10,980	
100-220 pg. 2	Basic Shell diameter	28"	$ 7,190	$ 7,190			
	Shell 10' 140#	10"	161	1,610			
	Front and rear heads			N/C			
	2" Nozzle 300#	1 ea.	95	95			
	6" Nozzle 300#	1 ea.	299	299			
	8" Nozzle 300#	2 ea.	367	734			
	3/4" U-Tubes, 300#	250	6.36	1,590			4/3 times 316 SS
	Alloy 20	1,220 ft^2	22.40	27,328			
	Support Plates	4	190	760			
	Support Saddles	2	227	454			
	ASME Stamp and Data Sheets			250			
	Total - Flash Condenser			$40,310		10,980	
	Installation Costs	32 mh	$ 30/hr	960			Based on tonnage, crew and crane time.

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Storage

ESTIMATE NO

SHEET NO. C-9 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	H2SO4 Storage Tank, Carbon Steel	1 ea.					
	72" x 12'-0" Shell - 5/8" thick	1 ea.	$ 259	$ 3,108	485	5,820	
	2 S.E. Heads	2 ea.		3,039	1,323	2,646	
	All Others	AR		6,147		4,233	
	Total H2SO4, Storage Tank			12,294		12,700	Use 7 tons
100-341	Hydrolyzer Water Storage Tank	1 ea.					
	78" x 20'-0" - 5/8" thick	1 ea.	270	5,400	525	10,500	
	2 S.E. Heads	2 ea.		3,406	1,545	3,090	
	All Others	AR		8,806			
	Total Hydrolyzer Water Storage Tank			17,612		20,385	Use 11 tons
100-341	Flash Tank	1 ea.					
	66" x 15' - 5/8" thick	15'	243	3,645	445	6,675	
	2 S.E. Heads	2 ea.		2,655	1,119	2,238	
	All Others	AR		6,300		4,457	
	Total Flash Tank			12,600		13,370	Use 7 tons
	Total All Storage Tanks			42,506			
	Installation - Labor	126 mh	$30/hr	3,780			
							Working hypothesis 2 x shell and head prices
							Labor based on tonnage, crew, and crane time

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Pumps

ESTIMATE NO

SHEET NO C-10 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS UNIT PRICE	COSTS AMOUNT	WEIGHT UNIT WT.	WEIGHT TOTAL	REMARKS
100-310	Acid Supply Pump						All motors for chemical
	(Chemical Metering) 60 G.P.H.	1 ea		$ 1,955			service, chemical
100-652	1-1/2 HP Motor	1 ea.		296			metering pump
100-286	Dilute Storage Transfer Pump						
	10 gpm 316 SS 30 ft head	1 ea		1,705			In-line, centrifugal
100-652	1-1/2 HP motor	1 ea.		296			
100-286	Condensate Transfer						
	10 gpm 316 SS 25 ft head	1 ea.		1,705			In-line, centrifugal
100-652	1-1/2 HP motor	1 ea.		296			
100-305	Sludge Transfer Cast Iron Sewage Pump						
	10 gpm 70 ft	1 ea.		1,130			Sewage Pump
100-652	5 HP motor	1 ea		378			
100-286	Sugar Solution Transfer, In-Line						
	10 gpm 316 SS 30 ft head	1 ea.		1,705			In-line centrifugal
100-652	1-1/2 HP motor	1 ea.		296			
100-286	Digester Water Feed Pump						
	300 gpm 316 SS 102 ft head	1 ea.		2,820			In-line centrifugal
100-652	15 HP motor, chemical service	1 ea.		810			
100-280	Tower Feed, Vertical Centrifugal Pump						
	50 gpm 316 SS 30 ft head	1 ea		1,125			Vertical, S.S. Centrifugal
100-652	1-1/2 HP motor	1 ea.		296			
	Total Pumps and Motors	7 ea.		14,813		2,800	
	Installation - Labor	162 mh		$ 2,916			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

Digestion - Bucket Elevator

ESTIMATE NO

SHEET NO. C-11 of 13

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-2	Bucket Elevator, Continuous Belt Size VCB-23	1 ea.					
pg. 7	Drive and V-Belt Guard, 27 rpm 3 HP	1 ea.	$ 1,870	$ 1,870	250	250	4 MH
pg. 9	Head Shaft and Tail Shaft	1 ea.	2,830	2,830	425	425	5 MH
pg. 10	Buckets - 24" x 8" x 3/16"	20 ea.	44.30	886	40	800	8 MH
pg. 10	Belt - 26" 105 nylon 6 ply	66 ft.	45.70	3,017			8 MH
	Belt Splicing Kit	2 ea.	86	172			6 MH
pg. 13	Elevator Casings						
	Head Section	1 ea.	750	750	650	650	2 MH
	Tail Section	1 ea.	840	840	730	650	3 MH
	Std. Section	2 ea.	1,445	2,890	1,260	2,520	12 MH
	Filter Section	6 ft.	121	726	105	630	6 MH
100-653	NEMA A, TEFC Explosion-Proof 3 HP, Class B Insulation Motor	1 ea.	1,188	1,188			22 MH
	Total Bucket Elevator			15,169		6,000	
	Installation - Labor	80 MH	$30/hr	2,400			Includes crane and crew rate

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Digestion - SO_2 Scrubber

ESTIMATE NO
SHEET NO C-12 of 13
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-115	SO_2 Scrubber, Size WH-65	1 ea	$ 4,710	$ 4,710	35	35	
	Q = 4,000 CFM N - 250						
	55"10 C Pressure Drop						
	R - 1 - 4.8 - 13 Say 9						
	R - 2 = .45 - 1.8 Say 1.13						
	R - 3 = .75						
	W - 1 = 36						
	W - 7 - 7.52						
	1/4" 304 SS Construction						
	Installation - Labor	8 MH	$30/hr	240			
100-373	Residue Storage Bin	1 ea	$26,000	$ 26,000			Concrete double sloping
	Subcontract Unit Price						100 ton capacity
							includes labor

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Digestion

ESTIMATE NO
SHEET NO C-13 of 13
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-341	Cyclone 2" Diameter x 4' T to T 316 SS	2 ea.	$ 6,288	$ 12,576	1,215	2,430	
	Installation - Labor	2 ea.	40 MH	80 MH	$30/hr	2,400	
100-135	Acid Dilution Mixer/Feeder Package Unit 500 gal. 304 SS, 20.8 gph	1 ea.	5,596	5,596	881	881	
	Installation - Labor	16 hrs.	$30/hr	480			
100-0	Dewatering Press Vendor 2 ton/hr 1 M wide	1 ea	83,000	83,000		20,000	
	Installation - Labor	240 MH	$30/hr	7,200			

QUANTITY SURVEY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION D

ACCOUNT

100-0 Equipment

Chemical By-Product Processing

ESTIMATE NO

SHEET NO D-1 of 5

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	T to T	PRESS.	TEMP.	MATL.	MATL. THICKNESS	CAP. AREA	MATL. RATING
100-341	Methane Recovery - Column	1 each	18"	45'-0"	50 psi	400°F	316 SS	1/2"		
100-341	Furfural Recovery Column	1 each	24"	45'-0"	50 psi	400°F	316 SS	1/2"		
100-230	Condenser	1 each			50 psi	400°F	316 SS/ C.S.		50 ft^2	
100-230	Condenser	1 each			50 psi	400°F	316 SS/ C.S.		150 ft^2	
100-230	Vent Condenser	2 each							50 ft^2	
100-220	Reboiler	1 each			50 psi	400°F	Alloy 20/C.S.			
100-220	Reboiler	1 each			50 psi	400°F	Alloy 20/C.S.			
100-341	Pump Surge Tank	2 each	24"	4'-0"	50 psi		316 SS	3/8"		
100-286	Pumps		FLOW	HEAD		MATL.	TYPE	DRIVE		
	Methane Reflux	1 each	5 gpm	65'		316 SS	in-line	1-1/2 HP		
	Methane Storage	1 each	5 gpm	35'		316 SS	in-line	1-1/2 HP		
	Furfural Reflux	1 each	5 gpm	70'		316 SS	in-line	1-1/2 HP		
	Furfural Storage	1 each	5 gpm	70'		316 SS	in-line	1-1/2 HP		
	Methane Storage Tank	1 each	6'	12'		316 SS		5/8"		
	Furfural Storage Tank	1 each	6'	18'		316 SS		5/8"		

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Chemical By-Product Processing - Recovery Columns

ESTIMATE NO

SHEET NO. D-2 of 5

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Methanol Recovery Column	2 ea.					Note: Estimate for 18" diameter pressure vessel are non-existant use 24" diameter. Use this estimate for both recovery columns
	Furfural Recovery Column						
100-342	Shell - 1/2" 316 SS x 3 C.S.	45"	$ 303	$ 13,635	131	5,895	
100-342	Semi-Eliptical Heads	2 ea.	1,932	1,932	286	286	
100-344	Angle Legs 6" x 6" x 1/2" Base Plates 8-1/2" x 8-1/2" x 1"	4 ea.	92	368	80	320	
100-347	Buttweld Nozzles						
	2" R.F. 150#	2 ea.	267	534	14	28	
	4" R.F. 150#	1 ea.	600	600	31	31	
	6" R.F. 150#	2 ea	765	1,530	57	114	
100-352	Tray Support Rings	30 ea.	426	12,780	22	660	Tray installation 67 x 30 - 2,010
100-359	Removable Type Trays	30 ea.	295	8,850	60	1,800	Use 3 ft. diameter
100-359	Ladder, Platform, and Support Clips	45 ea.	22	990			
	Lifting Lugs			210			
5-11	Caged Ladders and Circular Platform	1,610 lbs.	$ 1.40	2,254	1,610		
							Use 6 tons
	Total Methanol Recovery Column	1 ea.	43,686	43,683	11,000		
	Total Furfural Recovery Column	1 ea.	43,683	43,683	11,000		
	Installation - Labor	80 MH	30	2,400			Crane and crew rate $30/MH
	Tray Installation	60 trays	67	4,020			
	Total Recovery Columns	2 ea.		87,366	22,000		
	Total - Labor			6,420			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Chemical By-Product Processing - Condensers

ESTIMATE NO

SHEET NO. D-3 of 5

PREPARED BY J. Richards DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-230	Condenser A = 50 ft^2						
	Type 85-CD x 3/2 for 316 SS	1 each	11,400	11,400	1,050	1,050	12 mh
100-230	Condenser A = 150 ft^2	1 each	18,450	18,450	1,850	1,850	18 mh
	Type 85-E x 3/2 for 316 SS						
100-230	Vent Condensers A = 43 ft^2	2 each	5,290	10,580	700	1,400	2 x 12 mh
	Type 85-BS						
	Total Condensers	4 each		40,430		4,300	
	Installation Labor	54	30	1,620			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Chemical By-Product Processing - Bottoms Reboilers/Reflux Level Drums/
Pumps

ESTIMATE NO
SHEET NO. D-4 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-220	Reboilers	2 each	$21,203	$ 42,406	5,600	11,200	
	Typical BEU Exchanger						
	Use Page A-3 600# Rating, 400 ft^2						
	TOTAL REBOILERS			42,406		11,200	
	Installation Labor	48 mh	$30	1,440			
100-341	Pump Surge Tank	2 each	4,356	8,712	1,334	2,668	
	2" diameter x 4' T to T, 316 SS						
	same as page A-2						
	TOTAL TANKS			8,712		2,668	
	Installation Labor	80 mh	30	2,400			
100-286	Pumps - 5 gpm up to 70 ft hd,	4 each	1,705	6,820	400	1,600	
	316 SS Internal, in-line, centr.						
100-652	Motors, 1-1/2 HP	4 each	296	1,184			
	TOTAL PUMPS			8,004		1,600	
	Installation Labor	4 x 22 mh	30	2,640			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Chemical By-Product Processing - Methanol Storage Tank

ESTIMATE NO
SHEET NO. D-5 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Methanol Storage Tank						
	72" diameter x 12' T to T	1 each					
	316 SS shell 5/8" thick material	12'	$ 684	$ 8,208	485	5,820	
	2 each S.E. Heads	Pair	7,695	7,695	2,646	2,646	
	Nozzles 6" 150# RF	2 each	831	1,662	60	120	
	4" 150# RF	1 each	657	657	33	33	
	18" man way	1 each	3,174	3,174	358	358	
	Wear Plates	Pair	391	391	128	128	
	Saddles	Pair	1,163	1,163	650	650	
	TOTAL METHANE STORAGE TANK			22,950		9,755	
	Installation Labor (18 + (1.5 x 5))	26 mh	30	780			
100-341	Furfural Storage Tank						
	72" diameter x 18' T to T						∿ 305,000
	316 SS shell 5/8" thick material	18'	684	12,312	485	8,730	
	2 each SE heads	Pair	7,695	7,695	2,646	2,646	
	Nozzles 6" 150# RF	2 each	831	1,662	60	120	
	4" 150# RF	1 each	657	657	33	33	
	18" man way	1 each	3,174	3,174	358	358	
	Wear Plates	Pair	391	391	128	128	
	Saddles	Pair	1,163	1,163	650	650	
	TOTAL FURFURAL STORAGE TANK			27,054		12,665	
	Installation Labor (18 + (1.5 x 7))	30	30	900			
	TOTAL STORAGE TANKS			50,004			
	TOTAL LABOR			1,680			

QUANTITY SURVEY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION E
ACCOUNT 100-0 Equipment
Neutralization

ESTIMATE NO
SHEET NO E-1 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	T to T	PRESS.	TEMP.	MATL.	MATL. THICK.	CAPA.	MATL. RATING.
	Concentrated Sugar Solution Tank	1 ea.	12'	48'			316 SS	5/8"	40,000 gal	
	Dilute Sugar Solution Tank	1 ea.	12'	12'			316 SS	5/8"	10,000 gal	
	Sugar Solution Storage Tank	1 ea.	12'	48'			316 SS	5/8"	40,000 gal	
	Pumps		FLOW	HEAD	PRESS.	MATL	TYPE	DRIVE		
	Digester Transfer	1 ea.	50 gpm	102 ft		316 SS		5.0 HP		
	Neutralizer Transfer	1 ea.	200 gpm	30 ft		316 SS		7.5 HP		
	Sugar Solution Transfer	1 ea.	25 gpm	30 ft		316 SS		2.0 HP		
	Centrifuge Transfer	1 ea.	10 gpm	30 ft		316 SS		2.0 HP		
	Sludge	1 ea	200 gpm	30 ft		316 SS		7.5 HP		
	Fermentation Transfer	1 ea.	200 gpm	30 ft		316 SS		7.5 HP		
	Cascade & Sand Filter	1 ea.								
	Centrifugal Separator									
	Lime Storage Bin	1 ea.							50 Tons	
	Mixers, In-Line	4 ea.								
	Tubular Conveyor with Bag Breaker	1 ea.		40'	Model 200					
	Hopper			30" sq x 36" hi						

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Neutralization - Concentrated Solution and Sugar Solution Storage Tanks

ESTIMATE NO
SHEET NO. E-2 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Concentrated Sugar Solution	1 ea.					3 x C.S. Prices, 316 SS
	Shell 144" diameter x 48' (spot x-ray) 5/8" 316 SS	48'	$ 1,122	$ 53,856	965.7	46,354	
	2 Semi-Eliptical Heads	2 pr.	8,850	8,850		11,065	
	Support Legs	2 ea.	92	736	100	800	
	Nozzles						
	6" RF 150#	6 ea.	837	4,986	60	360	
	18" Manway	1 ea.	3,174	3,174	358	358	
	Platforms Not Required						
	Total Concentrated Sugar Solution Tank	1 ea.		71,602		58,938	Use $30/hr for composite crew and crane time
	Installation	80 MH	$30/hr	2,400			
100-341	Sugar Solution Storage Tank (equal to concentrated sugar solution tank)	1 ea.	71,602			58,928	
	Installation - Labor	80 MH	$30/hr	2,400			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Neutralization - Dilute Solution Storage Tank

ESTIMATE NO
SHEET NO. E-3 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Dilute Sugar Solution Storage Tank	1 ea.					
	316 SS 5/8" thick material						
	spot X-rayed						
	Shell, 144" diameter (spot X-rayed)	12'	$ 1,127	$ 13,462	965.7	11,589	
	2 S.E. heads (spot X-rayed)	pair	8,850	8,850	11,056	11,056	
	Support Legs	8 ea.	92	736	100	800	
	Nozzles						
	6" R.F. 150#	6 ea.	831	4,986	60	360	
	18" Manway	1 ea.	3,174	3,174	358	358	
	Total Dilute Sugar Solution Storage Tank	1 ea.		31,208		24,163	
	Installation - Labor (1.8 x 13) + 24	48 MH	$30/hr	1,440			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Neutralization - Pumps

ESTIMATE NO
SHEET NO. E-4 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-282	Digester Transfer Pump Single Stage, Centrifugal 50 gpm	1 ea.	$ 2,900	$ 2,900	365	365	
100-652	5 HP Nema, TEFC	1 ea.	350	350			
100-282	Transfer Pump (25 or 10 gpm)	2 ea.	2,700	5,400	180	360	
100-652	2 HP Nema, TEFC Motor	2 ea.	255	510			
100-282	Neutralizer Transfer, Sludge, and Fermitting Transfer Pump - 200 gpm	3 ea.	4,000	12,000	450	1,350	
100-652	7.5 HP Motor	3 ea.	426	1,278			
	Total Pumps	6 ea.		22,438		2,100	
	Installation - Labor	144 MH	$30/hr.	4,320			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Neutrlization - Centrifugal Separator Mixers

ESTIMATE NO
SHEET NO. E-5 of 5
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-0	Centrifugal Separator	1 ea.	$90,000	$ 90,000		3,000	
	Installation	80 MH	$30/hr	2,400			
100-0	Cascade and Sand Filter	1 ea.	130,000	130,000		28,200	
	Installation	240 MH	$30/hr	7,200			
100-0	Lime Storage Bin	1 ea.					
	Material	1,469 lb	.53	779		1,469	
	Weld	288 in.	.54	156			
		1,469 lb.	.20	294			
	Bin Total			779			
	Installation			450			
100-0	Mixers, In-Line	2 ea	1,500	3,000	300	600	
	Installation	80 MH	$30/hr	2,400			
100-0	Tubular Conveyor with Bag Breaker Hopper C.S.	1 ea.	2,700	2,700		2,000	
	Installation	40 MH	$30/hr	1,200			
	Total Installation						

QUANTITY SURVEY

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION F

ESTIMATE NO

ACCOUNT

SHEET NO F-1 of 6

100-0 Equipment

PREPARED BY MAHB DATE 10/81

Fermentation

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	RPM/HP	PRESS.	TEMP.	MATL.	MATL. THICK.	AREA CAPA.	
100-341	Yeast Mix Tank	1	6'x5'						1,000 gal	
100-145	Yeast Mix Agitator	1		1150/1.5						
100-282	Yeast Transfer Pump			5 HP					50 gpm	
100-145	Fermenter Tank Agitator	6		68/75						
100-341	Sterilization Tank	1	6'x5'						1,000 gal	
100-145	Sterilization Tank Mixer	1		1150/1.5						
100-341	Cleaning Chemical Tank	1	6'x5'						1,000 gal	
100-145	Cleaning Chemical Tank Agitator			1150/1.5						
100-341	Yeast Wash Tank		6'x5'						1,000 gal	
100-145	Yeast Wash Agitator			1150/1.5						
100-0	Yeast Wash Separator	1		50 HP						
100-220	Sugar Solution Cooler	1					C.S./SS			
100-341	Fermentation Tanks	6	12'x45'				C.S.		48,400	
100-341	Beer Storage Tanks	2	12'x45'				C.S.		40,000	
100-282	Transfer Pump Without Drive	1					316		200	
100-0	Yeast Clean Centrifuge	2					316		400 gpm	
100-651	Yeast Drive	2		50 HP						
100-282	Transfer Pump	8					316		500 gpm	
100-651	Drive	8		50 HP						

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Fermentation - Pumps

ESTIMATE NO
SHEET NO F-2 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-282	Yeast Transfer Pump 5 gpm	1 ea.	$ 870	$ 870	135	135	3 HP Drive
100-282	Transfer Pump 200 gpm	1 ea.	4,000	4,000	450	450	7.5 HP Drive
100-282	Transfer Pump 500 gpm	6 ea.	1,706	10,236	455	2,730	50 HP Drive
	Total for Pumps	8 ea.		15,106		3,315	
100-651	Drivers						
	3 HP NEMA "A" TEFC	1 ea.		250			
	7.5 HP NEMA "A" TEFC	1		420			
	50 HP NEMA "A" TEFC	6	1,940	11,650			
	Total for Drive			12,310			
	Total Pumps			27,416			
	Installation						
	2 (24) 48						
	6 (32) 192	240	$30/hr	7,200			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Fermentation - Fermenation, Beer Storage Tanks

ESTIMATE NO
SHEET NO. F-3 of 6
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-341	Fermentation and Beer Storage Tanks	8 ea.					
	12' diameter x 45' T to T						
	Carbon Steel Construction						
	144" diameter shell x 45'	45'	$ 420	$ 18,900	966	43,470	
	5/8" thick material						
	S.E. Heads	pair	4,925	4,925	11,056	11,056	
	Nozzles						
	6" RF 150 #	6 ea.	277	1,662	60	360	
	18" Manway	1 ea.	1,058	1,058	358	358	
	Support Legs	8 ea.	92	736	100	800	
	Total One Tank			27,281		56,044	Use 30 tons
	Installation (1.8 x 15) + 51 = 78	80 MH	$30/hr	2,400			
	Total for Fermentation and Beer Storage Tanks	8 ea.	27,281	218,248	56,044	448,352	
	Installation	8 x 80	$30/hr	19,200			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Fermentation Section - Yeast, Sterilization, Yeast Wash, and Cleaning Chemical Tanks

ESTIMATE NO
SHEET NO F-4 of 6
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Tanks, S-S 72" x 5' T to T	4 ea.					
	5/8" thick shell	5'	$ 729	$ 3,645	445	2,225	
	S.E. Heads	pair	7,965	7,965	1,119	1,119	
	Nozzles 6" RF 150#	3 ea.	831	2,493	60	180	
	Support Legs	4 ea.	92	368	100	400	
	Total One Tank	1 ea.		14,471		3,924	Use two tons
	Installation	40 MH	$30/hr	1,200			
	Total Yeast, Sterilization and Cleaning Tanks	4 ea.	14,471	57,884	3,924	15,696	
	Installation 40 x 4	160 MH	$30/hr	4,800			

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Fermentation - Agitators, Cooler

ESTIMATE NO
SHEET NO. F-5 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS UNIT PRICE	COSTS AMOUNT	WEIGHT UNIT WT	WEIGHT TOTAL	REMARKS
100-145	Agitators for all Tanks						
	Bath Homogenizer Mixer Model #6H with Drive	12	$ 5,600	$ 67,200	900	10,800	
	Total						
	Installation (12 x 32)	384	$30/hr	11,520			
100-220	Sugar Solution Cooler	1	22,613	22,613	1,850	1,850	
	Modify With 316 SS Tubes		4,000	4,000			
	Total for Cooler			26,613		1,850	
	Installation	20 MH	$30/hr	600			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-Equipment
Fermentation - Centrifuges

ESTIMATE NO
SHEET NO F-6 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-0	Yeast Cream Centrifuge Separator	2 ea.	$90,000	$180,000	3,000	6,000	$ 10,000 each for P&C
	Yeast Wash Separator	1 ea.	90,000	90,000		3,000	
	Total Centrifuges and Separator			$270,000		9,000	
	Installation - Labor	3 x 240	$30/hr	21,600			

MULTITECH

QUANTITY SURVEY

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION G
ACCOUNT 100-0 Equipment
Distillation Section

ESTIMATE NO
SHEET NO G-1 of 2
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	T to T	WIDTH	HEIGHT	LENGTH	SPACE	CAP.	TOTAL
100-0	Distillation Section									
	Beer Stripper/Rectifier		42"	75'						
	Anhydrous Tower and Reboiler		36"	80'						
	Hydrocarbon Stripper		24"	45'						
	Reflux Drum									
	Fusel Oil Batch Decanter									
	Tank									
	All Piping Instrumentation									
	Pumps									
	Exchangers									
	Total Size on Skids	2 ea			12'	12'	30'	15'		40'-30'
100-341	Ethanol Storage Tanks, C.S.	2 ea	144"	60'					50,000 gal	
100-286	Pump 200 gpm, 316 SS	1 ea.								

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Distillation Section

ESTIMATE NO
SHEET NO. G-2 of 2
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-0	Distillation Section	1 ea.	$545,000	$545,000	70,000	70,000	
	Installation - Labor	1,000 MH	$30/hr	30,000			
100-341	Ethanol Storage Tanks 50,000 gal, C.S. 5/8" thick	2 ea.					
	Shell, Spot X-Ray, C.S. 5/8" thick	60'	374	$ 22,440	965.7	57,942	
	2 ea. S.E. Heads	Pair	8,951	8,951	11,056	11,056	
	Legs and Base Plates	4 ea.	92	368	100	400	
	Nozzles						
	2" 150# RF	4 ea	91	364	14	56	
	6" 150# RF	2 ea.	277	554	60	120	
	18" 150# RF	1 ea.	1,058	1,058	358	358	
	Blind Flange 18"	1 ea	649	649	310	310	
	Total One Tank	1 ea.		34,384		70,242	
	Installation - Labor (59 + (0.8 x 6))	65 MH	$30/hr	1,950			
	Total Tanks	2 ea.	34,384	68,768	70,242	140,484	
100-282	Ethanol Transfer Pump	1 ea.	4,000	4,000	450	450	
100-652	7-1/2 HP, TEFC, Explosion-Proof, NEMA B, Class B Insulation	1 ea.	748	748	250	250	
	Total Transfer Pump			4,748	700		
	Installation - Labor	24 MH	$30/hr	720			

QUANTITY SURVEY

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION H
ACCOUNT
100-0 Equipment
Sugar By-Product Recovery

ESTIMATE NO
SHEET NO H-1 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	DIA.	T to T	PRESSURE	TEMP.	MATL.	MATL. THICKNESS	CAP. AREA	
100-0	First Stage Evaporator	1			50 psia	225°F	316		1,500	
100-0	Second Stage Evaporator	1			50 psia	250°F	316			
100-220	Stillage Preheater	1			50 psia	250°F	316		50 ft^2	
100-220	Preheater	1			50 psia	250°F	316		50 ft^2	
100-220	Molasses Preheater	1			50 psia	250°F	316		50 ft^2	
100-230	Condenser	1			50 psia	250°F	316		50 ft^2	
100-341	First Stage Flash Drum	1	2'	4'	50 psia	250°F	316			
100-341	Second Stage Flash Drum	1	2'	4'	50 psia	250°F	316			
100-341	Thin Stillage Tank	1	12'	24'			316		2,000 gal	
100-341	Molasses Storage Tank	1	12'	60'			316		50,000 gal	
100-282	Pumps									
	Transfer Pump	1					316		200 gpm	45' TDH
	Circulation Pump	1					316		1,000 gpm	100' TDH
	Circulation Pump	1					316		100 gpm	100' TDH
	First Stage Circulation Pump	1					316		50 gpm	100' TDH
	Second Stage Circulation Pump	1					316		50 gpm	45' TDH
	Transfer Pump	1					316		25 gpm	25' TDH
100-0	Steam Compressor	1			7 psi				88,500 lb/hr	

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Sugar By-Product Recovery - Pumps

ESTIMATE NO

SHEET NO H-2 of 6

PREPARED BY MAHB DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-282	Transfer Pump (200 gpm)	1	$ 4,000	$ 4,000	450	450	7-1/2 HP
100-282	Circulation Pump (1,000 gpm)	1	6,250	6,250	615	615	50 HP
100-282	Circulation Pump (100 gpm)	1	3,700	3,700	440	440	5 HP
100-282	First Stage Circulation Pump (50 gpm)	1	2,900	2,900	365	365	5 HP
100-282	Second Stage Circulation Pump (50 gpm)	1	2,700	2,700	180	180	2 HP
100-282	Transfer Pump (25 gpm)	1	2,700	2,700	180	180	2 HP
	Drivers						
	50 HP NEMA Design A TEFC	1	2,000	2,000	--	--	
	7-1/2 HP NEMA Design A TEFC	1	426	426	--	--	
	5 HP NEMA Design A TEFC	2	350	700	--	--	
	2 HP NEMA Design A TEFC	2	255	510	--	--	
	TOTAL PUMPS			$25,886		2,230	
	Installation						
	(5 x 24) + 1 x 32	152	30	$ 4,560	--	--	

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Sugar By-Product Recovery
Evaporator Section and Final Condensor

ESTIMATE NO
SHEET NO H-3 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-0	First Stage Evaporator						
	Second Stage Evaporator						
	Vapor Condensor and Steam Compressor						
	(Vendor Quote)			$246,041	42,000	42,000	
	Installation	160	$ 30	4,800			
100-230	Condenser	1	$12,300	12,300		1,850	
	Model 85-E STOKES, Inc.						
	Vertical Tube Surface						
	Condenser or receiver						
	Vacuum Type						
	Modify using 315 SS tubes			4,000			
	Total Final Condenser			16,300		1,850	
	Installation	18 MH	30	540			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment
Sugar By-Product Recovery - Flash Drum

ESTIMATE NO
SHEET NO. H-4 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
100-341	Flash Drums 316 SS	2	$ 4,356	$ 8,712	1,334	2,668	
	From page A-2						
	Installation 40 x 2	80	30	2,400			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
100-0 Equipment
Sugar By-Product Recovery - Tanks

ESTIMATE NO
SHEET NO. H-5 of 6
PREPARED BY MAHB DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-341	Thin Stillage Tank 316 SS	1					
	12' x 24" 5/8 Tank	24 ft	$ 1,260	$ 30,240	965.70	23,177	
	2 S.E. Head	pair	14,775	14,775	11,056	11,056	
	All Other	AR		7,000		1,767	
	Total Thin Stillage Tank			52,015		36,000	18 tons
	Labor	30	30	900			
100-341	Concentrated Solution Tank						
	12' x 60' 5/8 thick 316 SS	60 ft	1,260	75,600	965.70	57,942	
	SE Heads	2	14,775	14,775	11,056	11,056	
	All Others	AR		7,000		1,767	
	Total Concentrated Sulution Tank			97,375		70,765	36 tons
	Labor	88	30	2,640			
	Total for Tanks			149,390		106,765	
	Installation	118 MH	30	3,540			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE

100-0 Equipment

Sugar By-Product Recovery - Preheater

ESTIMATE NO

SHEET NO. H-6 of 6

PREPARED BY MAHB DATE 10/81

CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
	From Digester Water Heater						
100-200	Preheater Modify using 316 SS tubes	3	$21,205	$63,615	5,600	16,000	
	Total Preheaters	3		63,615			
	Installation (24 x 3)	72	30	2,160			
	Steam Compressor						Included in Evaporator Cost

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE SECTION I
General Costs

ESTIMATE NO
SHEET NO. I-1 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
1-0	Hydrolyzer/Neutralizer Building	6,000	$ 44	$264,000	--	--	All costs in this section
	6,000 sq. ft., use mid, structural						include labor
	steel frame						
	Boiler Building	3,920	40	156,800	--	--	
	3,920 sq. ft., us mid, reinforced						
	concrete						
	Fermentation and Distillation Bldg.	5,200	54	280,800			
	5,200 sq. ft., use high, structural						
	steel frame						
	Administration & Maintenance Bldg.	1,600	32.5	52,000			
	1,600 sq. ft., use mid, masonry						
	construction						
	Total			753,600			
2-0	Site Work						
2-14	Excavation and Backfill Class 1 Matl						
	Wood Storage 200 x 200 x 1	40,000 cft					
	Settling Ponds 100 x 100 x 10 x 2	200,000					
	Bldg. Footings 6' x 2' x 1072	12,862					
	Coal Storage 100 x 100 x 1	10,000					
	Bldg. Pads 16,720 x 1	16,720					
	Plus Add	20,000					
	339,582 cft						
	12,600 cy	12,600 cy	3.52	44,352			
1-0	Land @ Butte Industrial Park	11.5 acres	9,000	103,500			

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO I-2 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
3-0	Concrete						
3-5 pg. 25	Wood Storage 200' x 200' x 8"	988 cy	$166.50	$164,502			
	Wood Process 200' x 200' x 8"	988 cy	166.50	164,502			
	Coal Storage 100' x 100' x 8"	247 cy	166.50	41,126			
	Various Pads 10' x 20' x 10' x 8"	50 cy	166.50	8,325			
	Total			378,455			
2-40	Water Distribution Ductile Iron Pressure Pipe						
	6" pipe	500'	8.79	4,395			
	4" pipe	100'	6.87	687			
	6" fittings	25 ea.	300.00	7,500			
	4" fittings	5 ea.	200.00	1,000			
	6" valves	5 ea.	500.00	2,500			
	4" valves	5 ea.	400.00	2,000			
	Reduced pressure backflow for 4" @ boiler	1 ea.	2,744	2,744			
	Total			20,826			
2-43	Asphalt Concrete 4" asphalt concrete 6" cement treated base	8,000 ft²	2.19	17,520			
	Total			17,520			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO. I-3 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
15-37	Sewage and Drainage						
	Site Drainage 6" PVC	1,000'	2.30	$ 2,300			
	Tees	6 ea.	57.24	343			
	Sewage Disposal 6"						
	Cast Iron Drain	1,400'	7.53	10,542			
	200' to settling pond from process						
	400' to sewer main						
	800' from clearing to settling pond						
	Fittings	50	60.	3,000			
	Total			16,185			
15-47	Process Piping						
	6" pipe 304 L S.S.	2,000'	67.75	135,500			
	4" pipe	4,000'	37.30	149,200			
	2" or smaller	12,000'	8.93	107,160			
	Fittings						
	6" pipe 304 L Buttweld 150	200	345.	69,000			
	4' pipe Buttweld 150	400	188	75,200			
	2" or smaller socket weld 3,000	1,200	200	144,000			
	Valves						
	6" pipe 150# flanged	20	2,237	44,740			
	4" pipe 150# flanged	40	1,264	50,560			
	2" or smaller socket weld	120	328	39,360			
	Total			814,720			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO I-4 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT.	TOTAL	
15-50	Instrumentation and Control						
	6" control valves	5	$ 3,356	$ 16,780			
	4" control valves	10	2,047	20,470			
	2" control valves	20	1,090	21,800			
	Liquid level gages	20	388	7,760			
	Pressure gages	20	100	2,000			
	Thermowells	20	175	3,500			
	Flow transmitters	5	1,100	5,500			
	Pressure transmitters	10	1,000	10,000			
	Temperature transmitters	10	1,000	10,000			
	Level transmitters	5	1,500	7,500			
	Control Panels	5	3,713	18,565			
	7'-6" high x 4'	4 ft	310	1,240			
	Annunciator adapter	1	520	520			
	Alarm Horn	1	50	50			
	Alarms	6	110	660			
	Annunciators	1	443	443			
	Labor	40	20	800			
	Instrument Piping (Control Valves)	35	365	12,775			
	(Instruments)	10	600	6,000			
	(Tubing)	45	89.60	4,032			
	(Level gage installation)	20	204	4,080			
	Total			150,762			
15-76	Hangers and Supports						
	Brackets	100	2,436	2,436			
	Pipe anchor	100	1,799	1,799			
	Clevis hangers	100	443	443			
	Installation - Labor						
	(75 + 16 + 75)	166	18	2,988			
	Total			7,666			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO. I-5 of 6
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
16-0	Power Distribution						
	Underground fiber conduit systems	150	$ 667	$ 1,000			
	15,000 V armored cable	150	28.67	4,300			
	Service entrance 4,000 amp 4 wire	2 sections	3,713	7,426			
		40	18	720			
	Circuit breakers 800	5	5,189	27,445			
	Main circuit breaker panels	5	3,230	16,150			
	800 amps - 3 PH 4 wire						
	PVC conduit 3"	1,200'	9.90	11,880			
	600 V amored cable	1,200	5.60	6,720			
	3/4" conduit	8,000'	.80	6,400			
	8/3 standard stranded	8,000'	2.29	18,320			
	Motor control centers						
	10-15 HP SS nonreversing	6	5,000	30,000			
	Total			130,361			
16-24	Instrumentation Wiring 24 pair	8,000	2.43	19,440			
	Conduit 3/4"	8,000	.80	6,400			
	Total			25,840			

MULTITECH

ESTIMATE WORK SHEET

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO I-6 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
2-60	Settling Ponds (subcontract price)	1,000'	$ 25.56	$ 25,560			
1-0	Caterpiller 966-D Wheel loaders 4-yard bucket	3 ea.	167,000	501,000			
5-0	Miscellaneous Structural Steel 25 tons - 50,000 lb	50,000 lb	.53	26,500			
	Weld	24,000"	.52	12,480			
	Installation	50,000	.20	10,000			
	Total			48,980			

ESTIMATE WORK SHEET

MULTITECH

PROJECT FUEL ETHANOL PRODUCTION FROM WOOD WASTE
General Costs

ESTIMATE NO
SHEET NO. I-7 of 7
PREPARED BY J. Richards DATE 10/81
CHECKED BY DATE

ACCOUNT	DESCRIPTION	QUANTITY	COSTS		WEIGHT		REMARKS
			UNIT PRICE	AMOUNT	UNIT WT	TOTAL	
100-0	Boiler T600P CNB Tri-Fuel	5 ea.	$240,000	$1,200,000	46,000	230,000	
	20,000 #/hr, 150 psi						
	complete with stoker						
	Installation - Labor	400 MH	$30/hr	12,000			
5-10	Railroad Unloading Hopper						
	Material	2,983"	.46	1,352		2,938	
	Welding	288"	.86	248			
	Installation	2,938	.20	588			
	Total Hopper	1 ea.		1,352		2,938	
	Installation			836			
100-7	Conveyors - 30'	2 ea.	12,859	25,718	6,972	13,944	
	Installation - Labor	2 ea.	3,540	7,080			
5-10	Stoker Feed Bin						
	Material	12,240#	.46	5,631		12,240	
	Welding	1,152"	.86	995			
	Installation	12,240#	.20	2,443			
	Total Bin	1 ea.		5,631		12,240	
	Installation - Labor			3,443			
	Boiler Total			1,232,701			
	Installation - Total			23,359			

DNRC 451-811,
AMENDMENT NO. 6

FUEL GRADE ETHANOL PRODUCTION USING WOOD WASTE (RESIDUES) AT SELECTED SITES IN MONTANA

FEASIBILITY STUDY - FINAL REPORT
VOLUME I: EXECUTIVE SUMMARY

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1.0 EXECUTIVE SUMMARY AND INTRODUCTION

1.1 SUMMARY

Three towns in Montana were studied for their possible ability to support a small-to-medium plant that would make fuel-grade ethanol (FGE) from wood: Anaconda, Lincoln, and Livingston.

A screening and evaluation method was devised to determine whether enough feedstock was available to allow economic plant operation. Wood wastes were considered the most likely feedstock, although straw was also considered. The major resource costs when using forest residues is the collection and transportation to the plant site, which have a very limiting effect on plant size. If supplemental funds or concentrated sources of wood waste, such as mills, are available, then larger collection areas and larger plants are possible. From just the waste available for collection in the forest, the possible plant sizes at the three study locations are the following:

Location	Maximum Gallons of Fuel Alcohol Per Year
Anaconda	1,340,000
Lincoln	775,000
Livingston	190,000

The wood-chipping plant at Livingston was not considered in the waste wood availability analysis, but could be a valuable fuel source if competitive demands did not exclude it, either through availability or cost. Other resources, such as mills wastes, wood chips, or straw, could increase plant feasible capacity to 900,500 gallons per year (gpy) for Lincoln and 340,000 gpy for Livingston.

The wood-to-alcohol conversion process used as the basis for this study was a modified Madison process. The Madison process has been commercially used in the past and was updated with obvious modern technological improvements to serve as the cost model, and for the estimation of the amount of dry wood required to produce a gallon of fuel alcohol. The process is detailed in the Milestone 3 Report. A plant cost curve was established for capacities ranging from 0.2 million gallons per year (Mgpy) to 2.5 Mgpy. Specific cost estimates (in 1984 dollars) were made for four plant sizes:

Capacity in Mgpy	Estimated Cost, Million $
0.2	3.1
0.775	5.8
1.25	7.0
2.50	10.3

A significant reduction in cost may be achieved by using second-hand equipment, and this effect is evaluated in the financial analysis. Also, as shown above, increases in plant capacity significantly reduce costs.

Environmental impacts and the requirements for permitting and licensing were evaluated. The agencies, procedures and standards that would be necessary before operation were identified. The impacts identified were not unique and appear to be conventionally controllable. Air emissions would be primarily those associated with a typical small steam plant. Liquid wastes would be largely waste water that would have to be treated prior to off-site disposal. No special treatment is indicated. Solid wastes from FGE plants are classified non-hazardous so conventional waste handling/disposal practices will be adequate. Quantities could be reduced by sale of most of the solid material as animal feed.

Although the permitting and licensing period would be lengthy, no special problems are foreseen. Conventional engineering design and good operational practices could ensure environmental acceptability.

The economic analysis of the four plant sizes showed that a capacity of 1.25 Mgpy is marginally economic while plants below that size would require dramatic changes in technology and fuel costs to be a reasonable investment. The economies of scale are very apparent, as the 1.25 Mgpy plant would have a payout term of a little more than twice the three years required by the 2.5 Mgpy plant.

Besides increasing plant size to improve economics, several other achievable measures could be taken: 1) second-hand equipment saves about 36% or $2.8 million at the 2.5 Mgpy size; 2) a concentrated source, i.e., a mill, lowers fuel costs; and 3) low interest rates and minimal the amount of conventionally borrowed money. Plant economics are the most sensitive to the fuel cost and the cost of money.

These general guidelines will create better plant economics: 1) use second-hand equipment, 2) obtain loans at an overall interest rate of 14% or less, 3) keep wood costs close to $20/ton or less, 4) increase plant capacity to 1.75 Mgpy or higher, 5) use supplemental feedstock such as paper waste to increase capacity and to provide a more secure fuel supply, and 6) integrate the FGE plant into other processes.

1.2 INTRODUCTION

The study discussed in this report was funded by a grant received from the Montana Department of Natural Resources and Conservation (DNRC) to MultiTech, Inc. of Butte, Montana (Montana DNRC, 1982). The Energy Division of DNRC is the immediate technical and contract monitor. The study period began on December 7, 1982, and was concluded on April 30, 1985.

In Part I of the study, MultiTech conducted detailed technical and economic feasibility studies for a 2.5 Mgpy FGE facility to be located in the vicinity of Anaconda, Montana. The results of the study indicated that use of a modified Madison residue-to-ethanol conversion process was technically feasible. However, the estimated quantity of residue feedstock did not appear sufficient to support a 2.5 Mgpy operation (MultiTech, 1982). Thus, the original grant agreement was amended to add a Part II which researched the following: 1) a recommendation of smaller FGE production capacities at Anaconda; and 2) evaluation of the technical and economic feasibility of FGE production at various scales of operation in the Lincoln and Livingston areas of Montana.

The data used and recommendations made (to the DNRC) regarding the outcome of the above studies was assembled and submitted in milestone reports. Part II activities were divided into six separate and discrete milestones as shown below:

- Milestone 1: The following information or analyses related to the Lincoln and Livingston sites was collected or performed, and submitted to DNRC:

- Description of total and post timber harvest (residue) waste wood characteristics for the areas around Lincoln and Livingston;
- Estimation of residue gathering and transporting costs in each area;
- Boundaries of residue supply areas, as determined through economic models using cost estimates of residue collection and hauling, and the competitive price that would be paid for the residue by other users;
- Detailed determination of the residue characteristics within the economically feasible hauling areas around Lincoln and Livingston; and
- Estimation of the annually averaged production of wood waste residues within these hauling areas.

- Milestone 2: For the Lincoln and Livingston sites, the following were submitted to DNRC:
  - Inventory of other potential sources of wood fiber, e.g., mill wastes;
  - Evaluation of the competition from other resource users on the wood waste supply in each site's economically feasible residue recovery area; and
  - Estimation of the range of FGE production capacities apparently supportable by the estimated feedstock base for each site area.

- Milestone 3: A written recommendation for DNRC on the specific FGE production capacities for each area, preliminary engineering designs, and cost estimates were prepared for the three sites (including Anaconda). The information and analyses submitted to the Department included:
    - Determination of feedstock and process materials required for operation and calculated material balances for each designated operating capacity;
    - Preparation of preliminary engineering designs, including schematic drawings and discussion of major plant subsystems;
    - Estimation of capital and construction costs for each designated capacity; and
    - Estimation of manpower requirements for each plant capacity.

- Milestone 4: For the largest feasible FGE plant size in each of the three areas, preliminary environmental and regulatory planning results were discussed:
    - The identification of authorizing agencies and required permits and licenses from federal, state, county, and local authorities;
    - Description of the application procedures to be followed in obtaining the pertinent licenses and permits, including time and cost estimates associated with preparing such applications;
    - Identification of the pertinent environmental protection standards, and the probable degree of project design compliance with these criteria;
    - Identification of environmental impacts and environmental resources of special concern for each of the three site areas; and

  - Identification of possible remedial measures to mitigate adverse environmental impacts at the three site areas.

- Milestone 5: For each facility size specified by DNRC from the recommendations in Milestone 3, the following economic analyses were performed:
  - Estimation of annual operating and maintenance costs;
  - Estimation of annual payments necessary to retire debt;
  - Estimation of revenue costs;
  - Estimation of rate of return;
  - Estimation of facility input and output requirements, such as the cost of wood fiber; and
  - Presentation of the results for various sensitivity analyses of the project's economies-of-scale, variability in cost of wood residue feedstock, and influence of interest rate(s) on project viability.

- Milestone 6: Final Report. The data and analyses contained in the preceding milestone reports have been integrated into a final written report, which is hereby submitted to DNRC. This report describes the overall economic feasibility, technical practicality, and general advisability of operating FGE facilities using wood wastes as feedstock at the three sites. The major chapters of this Executive Summary include:
  - Resource Availability;
  - Plant Scaling and Costs; and
  - Environmental Concerns and Permitting.

2.0 SUMMARY OF VOLUME II: RESOURCE AVAILABILITY

Volume II was prepared from information presented in Milestones 1 and 2. Milestone 1 concentrated on timber harvest residue, while Milestone 2 considered alternate sources of feedstock for the potential FGE sites.

2.1 TIMBER HARVEST RESIDUE INVENTORY STUDY

2.1.1 Objectives

The Milestone 1 Report was prepared with three major objectives in mind. The first objective was to inventory timber harvest residue potentially available within 50 miles of the Lincoln and Livingston sites. Included in this inventory was the general characterization of each location, quantity, and physical characteristics (e.g., number and average volume of residue pieces per acre) of the residues. The second objective involved computer analysis of the above data, along with estimated residue gathering and transportation costs. Such modelling results allow determination of the area within which the residues are economically harvestable. The third objective was to adjust the wood waste inventory estimates for user's competition and various environmental attributes which affect the magnitude of the resource base.

2.1.2 Summary

Three major objectives were accomplished during the course of this study. These objectives included the characterization, economic analysis, and estimation of total and annual harvest residue supplies within defined distances around Lincoln and Livingston, Montana.

The reconnaissance-level characterization of the various forest cover types per site was accomplished largely via literature review and contacts with local land management personnel. Particular data representative of "average" forest conditions then were used in two separate economic models.

The first model used the USDA, Forest Service Method (1977); although designed primarily for appraising saw timber harvest and transport costs, the equivalent costs for residue acquisition can be extrapolated with this method. The second approach used a model developed by Dr. Richard P. Withycombe of the University of Montana; the model allows computation of costs associated with harvesting of forest residues based on several key characteristics of the residues and the logging area (Withycombe, 1980). In both modelling cases, the critical assumption was that the maximum affordable ceiling price at the FGE plant gate was $43.60 per green ton; such an assumption was based upon the previous residue analysis by MultiTech (1982) and discussion found in Keegan's The Cost and Availability of Forest Residue in the Northern Rocky Mountains (1981). The modelling results were used to determine an economically feasible haul distance for each FGE site.

Given these distances, total residues available for each site were determined via inspection of land ownership/commercial timberland maps. The estimation of annual residue availability for FGE production required recognition of certain institutional constraints. Such constraints include various economic, environmental, and other technical factors that remove portions of the total resource base, precluding residue utilization by the FGE facility. An overview of the site-specific results from the above efforts is presented below.

- Lincoln Study Area

  In regard to the Lincoln site, the following major forest cover types were identified: ponderosa pine-Douglas fir/bunchgrass on warm/dry sites; Douglas fir-lodgepole pine on cool/dry sites; lodgepole pine-subalpine fir on cool/moist sites; and "bottomland" sites (dominated by Engelmann spruce, grand fir, and western larch).

  Application of the USDA model indicated residue could be economically hauled for distances ranging from 11 to 57 miles. Depending upon the assumptions applied to the Withycombe model, the profitable residue haul distance varied from 0 to 20 miles. A conservative value of 22 miles was derived, and should be taken as a credible value for any future study in the area.

  From the assessment of the ownership/timber map, there appears to be approximately 268,320 acres of commercial timber land (CTL) within 25 miles of Lincoln, and a total acreage of 1,051,680 acres within 50 miles. Given the relative proportions of major forest types derived from literature review, total residues present within 25 to 50 miles are about 5.7 and 22.3 million tons, respectively. The anticipated annual production within 25 miles of town is about 29,442 tons; within 25 to 50 miles, 79,139 tons. Using the previously calculated value of 76 green pounds of residue feedstock per gallon of FGE produced (MultiTech, 1982), annual FGE production would vary from .775 to 1.35 million gallons per year. The modelling results indicated that waste wood could be economically hauled for 22 miles, and so it is recommended that the lower FGE value be used in the engineering design/plant capacity studies.

- Livingston Study Area

In regards to the Livingston site, the following major forest cover types were identified: 1) ponderosa pine/juniper on dry sites; 2) Douglas fir-lodgepole pine on cool/dry sites; 3) Engelmann spruce-subalpine fir-lodgepole pine on cool/moist sites; 4) "bottomland" sites; and 5) "subalpine" sites (dominated by white-bark pine and limber pine).

Application of the USDA model indicated a maximum economic haul distance of about 84 miles, approximately twice the distance cited in Tillman (1978); however, the 84-mile value is possible when considering saw timber operations. Depending upon the assumptions used with the Withycombe model, the profitable haul distance varied from under 4 miles to about 43 miles. As with Lincoln, a conservative figure of approximately 22 miles was selected as an appropriate haul distance maximum. From inspection of the ownership/timber map, there appears to be about 84,960 acres of commercial timber land within 25 miles of Livingston, and a total acreage of 293,280 acres within 50 miles.

Given the relative proportions of major forest types as derived from literature review, total residues within 25 and 50 miles should be about 1.4 and 4.9 million tons, respectively. The anticipated annual production within 25 miles of town is about 7,200 tons; similarly, about 24,500 tons will be produced within the area from 25 to 50 miles from town. Using the 76 pounds residue per gallon FGE conversion factor, estimated annual FGE production could vary from about 189,500 gallons to a "best case" of 327,000 gallons. Given the uncertainties inherent in the resource and economic analyses, it is recommended that the lower production FGE value be used in the engineering design/plant capacity studies.

2.1.3 Conclusions

The results presented in Section 3.0 of Milestone 1 should be taken as "first approximation" (or "ball park") estimates of the total and annual residue resource bases available to each potential FGE plant site. The total residue estimates per site are probably accurate to ± 15 percent, given the comprehensive and accurate nature of the information sources. The combination of more accurate ratios of forest cover types, better definition of harvest methods utilized, and the forthcoming publication of field data gathered by James Howard et al. (phone conversation, April 27, 1983) could improve the estimates considerably.

The annual production estimates are probably accurate to ± 30 percent. The basis for this conclusion is two-fold. Firstly, the economic models used information characteristic of a "representative" stand of commercial timber;

it is reasonable to assume "real world" variation from the "representative" data of ± 20 percent. As shown in Section 3.0 in the Milestone 1 report, the results from the models are sensitive to the assumptions used. The averaged values for haul distances attempt to compensate for such variability, but the resulting accuracy (in the adjustment) is difficult to quantify. Secondly, the ceiling price used (i.e., an economic maximum of $43.60 per green ton) could vary disproportionately over time, relative to residue harvest and transport costs. This disproportionate variation would arise from varying intensity of competition with other potential residue users, particularly large-scale industrial plants, such as the makers of paper. Such competition could reduce the distance the residues could be economically hauled to a given FGE plant. It is assumed that long-term competition could affect even the moderate economic haul distance by ± 10 percent from year to year.

Therefore, the annual supply of timber harvest residues could vary considerably from the long-term annual averages described in Section 3.0 of the Milestone 1 report. Given the risk of investing in an FGE facility, it is recommended that the more pessimistic ("worst case") annual estimates be used in determining facility capacities at the two sites. In this manner, the most likely feedstock supply can be planned on, and unpleasant surprises (e.g., adverse supply situations/plant shut-down) can be minimized. The above caveats are speculative, so the residue resource estimates in Milestone 1 should be taken as the best available estimates of the more pessimistic case. Site-specific estimates are summarized below.

- Lincoln Study Area

Given the assumed proportions of major forest cover types, total residues present within the moderate haul distance of approximately 25 miles are about 5.7 million tons of green wood. The "optimistic" and "pessimistic" annual production figures were calculated to be 51,386 green tons and 29,442 green tons, respectively. Using an assumed FGE conversion factor of 76 pounds of green wood per gallon of FGE (Multi-Tech, 1982), the above tonnage figures translate to about 1.35 million and 775,000 gallons per year. As discussed above, the lower value is recommended for use in determining the feasible plant capacity.

- Livingston Study Area

Given the assumed proportions of major forest cover types, total residues present within the averaged haul distance of approximately 25 miles are about 1.4 million green tons. The "optimistic" and "pessimistic" annual production figures were calculated to be 12,413 tons and 7,199 tons, respectively. Using the above wood-to-FGE conversion factor, the above tonnage figures translate to about 327,000 and 189,500 gallons per year. Again, the lower value is recommended in peforming the engineering design/plant capacity studies.

2.2 MILL WASTE AND WOOD FIBER RESOURCE INVENTORY STUDY

2.2.1 Objectives

The Milestone 2 Report was prepared with two major objectives in mind. The first objective was the estimation of economically available quantities of mill residues present within a prescribed distance from the potential FGE sites located at Lincoln and Livingston. The second objective was the estimation of processable (i.e., "secondary" sources) of wood fiber wastes economically available for each FGE facility. In response to these objectives, the report described the locations' physical characteristics and assessed the economic desirability of using the defined wastes in site-specific FGE production operations.

2.2.2 Summary

Two key objectives were accomplished during the course of this study. First, the various sources of residues not directly associated with timber harvest were inventoried and their respective annual production rates of economically available materials established. Secondly, the above findings were integrated with the Milestone 1 study results to estimate plant capacity at the Lincoln and Livingston FGE study sites. The first objective, the reconnaissance-level characterization of the wastes, was accomplished largely via telephone interviews of sawmill operators and recycling center managers, along with a review of readily available literature. The second objective included the preparation of probable annual average and perceived variation in site-specific FGE plant capacities. These efforts focused on the perceived uncertainties inherent in each of the residue category estimates utilized to forecast overall plant capacity (per study site).

In regards to the Lincoln site, the annual production of uncommitted sawmill wastes appears to range between 1,726 green tons and 3,822 green tons; for reasons discussed in Subsection 3.1.1 of Milestone 2 (regarding competition with other industrial users), the lower value is given more credence. The prices of these residues range from about \$6.10 per green ton for hog fuel-type material to about \$30.00 per green ton for pulping chip material. Tractor-trailer transport costs are in the range of \$0.05 per ton-mile. The 1980-based estimate of fermentable materials salvaged from municipal landfills came to approximately 30,252 green tons per year (tpy); assuming that the major cost arises from transportation from a given landfill to the FGE site, the wastes range in value from \$0.84 to approximately \$47.48/ton. However, perceived institutional and technological constraints reduce the resource base by 90 percent; thus, about 3,025 tpy of wastes were assumed to be available for FGE production. The monthly average for recycled newsprint and corrugated containers totals approximately 185 tons. The price charged by the centers for such materials will probably be at least \$45.00/ton, while haul costs are in the neighborhood of \$0.03 per ton-mile. However, the intense competition and volatile market for these paper residues largely eliminates their consideration as a reliable source of FGE feedstock. Furthermore, the inventory methods used in estimating municipal waste quantities probably includes the above types of paper wastes. Potentially, about 20 tpy of such residues probably could be received at the FGE plant site. In summary, about 4,771 green tpy of uncommitted, economically available mill wastes appear to be ready for conversion to FGE.

The Milestone 1 Report presents an annual estimate of 29,442 green tpy of timber residues being economically accessible within a 25-mile radius of Lincoln (MultiTech, 1983). The addition of the timber and waste residue production figures totals to 34,213 green tpy. By using an average fiber-to-FGE conversion ratio of 76 green pounds/gallon FGE, the above tonnage is equivalent to about 900,300 gpy (MultiTech, 1982). However, this capacity figure should be regarded cautiously, as it does not fully incorporate the uncertainties inherent in each of the various residue production estimates. As discussed in subsection 4.2.1, the predicted plant capacity could vary from 542,500 gpy to 1,202,000 gpy, depending upon the assumptions made. Overall, it was concluded that a reasonable capacity estimate is between 872,250 gpy (i.e., the arithmetic average of the above two figures) and the previously derived 900,300 gpy figure.

In regards to the Livingston site, the annual production of uncommitted sawmill wastes appears to range between approximately 2,484 and 5,880 green tons; for reasons discussed in subsection 3.2.1, the lower value is recommended for FGE plant capacity planning. As the major industrial purchasers of the residues are the same as those purchasing the Lincoln-related wastes, the unit and tractor-trailer costs are about the same as discussed previously. The 1980-based estimate of municipal wood fiber recovery is about 31,816 green tpy. If transportation costs from a given landfill to the FGE site are assumed to be twice those incurred prior to departure from the landfill, then the wastes will range in value from $1.26/ton to about $46.22/ton. As discussed for the Lincoln site, a conservative estimate is that only 10 percent (about 3,182 tpy) of the wastes will actually be received at the plant gate. The monthly average throughput for recycled newsprint and old corrugated containers totals approximately 195 tons. The price charged by the centers for such materials appears to average about $72.50 per ton, excluding transport costs; haul costs are in the range of about $0.03 per ton-mile. As discussed for the Lincoln site, it was assumed that 20 tpy would be received at the FGE feedstock supply.

The Milestone 1 Report presents an annual estimate of 7,200 green tpy of timber residues being produced within a 25-mile radius of Livingston (Multi-Tech, 1983). The addition of the timber and waste residue production figures totals to 12,886 green tpy. By using an average fiber-to-FGE conversion ratio of 76 green pounds/gallon FGE, the above tonnage is equivalent to about 339,100 gpy (MultiTech, 1982). However, recognition of uncertainties inherent in the various estimates causes the estimated capacity to vary from 132,650 gpy to about 478,200 gpy. Overall, it is recommended that FGE plant capacity be set in the range between 305,400 gpy (i.e., the arithmetic average of the "pessimistic" and "optimistic" figures) and the previously derived figure of 339,100 gpy.

2.2.3 Conclusions

The "ball park" approximations for the annual production of each of the three waste fiber categories present within each of the defined study areas are derived in Milestone 2. They are approximately 4,771 tons per year for Lincoln, 5,686 for Livingston, and 7,725 for Anaconda. The collective annual estimate of uncommitted waste available for each site is probably accurate to ± 55 percent of the "true," long-term value. A three-part rationale is offered in support of this conclusion.

First, many of the small sawmill operators contacted do not keep accurate records of the amount of coarse and fine waste they produce. The use of operator-based estimates, along with "second-hand" estimates made by the author (using cursory data received from the operators), could result in collective errors of ± 20 percent.

Secondly, the processable waste estimates could be in error of ± 25 percent. The 1980 and 1990 municipality-specific annual waste production rates used demographically based population projections and per capita waste production rates based upon the relative size of the given community (Henningson et al., 1976a). A comparison of projected vs. estimated (i.e., censused) 1980 population figures for Helena, Livingston, and Bozeman generated ratios of approximately 1.60, 1.30, and 1.68, respectively (Dr. Phil Brooks and Ms. Patricia Roberts, personal communications). Taken at face value, these ratios indicate that the fermentable waste estimates presented in Section 3.0 of Milestone 2 exceed the actual case. Unfortunately, econometric-based modeling of population growth and assessment of institutional and technologic factors (e.g., Baum et al., 1974) on per capita waste production rates, for any given community, was beyond the scope of this project. It is suggested that such modeling and assessment efforts be made following a general conclusion that FGE production (at a particular scale) is economically viable at one or both of the study sites.

Thirdly, the information acquired from the recycling centers is probably accurate to ± 10 percent of the actual values. The various managers provided approximations based on past experience of the magnitude of materials processed. Although acquisition of more accurate data is possible, an extrapolation of such information into a 25- to 30-year future would be difficult.

In summary, the lower estimate (of a range in estimates) for each waste category (per site) should be used in deriving an overall conservative evaluation of feedstock availability for FGE production. Clearly, such site-specific extrapolations into the future assume that annual production levels of waste will not fall below present levels. Conclusions specific to each of the study sites are elaborated upon in the following subsections.

- Lincoln Study Area

  Subsection 3.1.1 of the Milestone 2 Report presented the rationale behind use of the lower range estimate of approximately 1,726 tpy for uncommitted sawmill residues. In regards to useable waste paper production, the arguments from Section 4.1 of Milestone 2 are applied to justify use of the 1980-based estimate of 30,252 tpy (Subsection 3.1.2). However, concerns over cost-effective waste collection and handling methods, plus seasonal variability in supply and potential market competition, dictate that such contributions to FGE feedstock not exceed 10 percent of the amount potentially available (MultiTech, 1982, pp. 4-33, 4-34). Thus, approximately 3,025 tpy of the economically available waste will be supplied "at the facility gate". Given the perceived competition for recycled waste paper products, purchases of amounts exceeding 20 tpy do not seem reasonable (Subsection 3.1.3). Furthermore, there is a strong likelihood that the municipal waste estimate already includes waste paper materials, given the methodologies used by Henningson et al., 1976 a,b. A summation of the respective residue production estimates yields an overall value of approximately 4,771 tpy.

- Livingston Study Area

  Subsection 3.1.2 of the Milestone 2 Report presented the rationale for selecting the lower range estimate of about 2,484 tpy for uncommitted sawmill residues. In regards to fermentable waste production, application of the above discussion (Subsection 4.1.1) results in an estimate of approximately 3,182 tpy of materials economically accessible to the FGE production site. Finally, purchases of recycled waste paper products in amounts exceeding 20 tpy do not seem feasible. A summation of the respective residue production estimates yields an overall value of approximately 5,686 tpy.

2.2.4 Recommendations

In order to estimate site-specific FGE production capacities, two important factors must be known. These factors are: 1) total feedstock availability; and 2) approximate fiber-to-ethanol conversion efficiencies. The first factor is addressed by integrating the results (per FGE site) of the Milestones 1 and 2 reports. Given the similarity in feedstock properties between the Anaconda site and the two presently considered sites, it will be assumed that approximately 76 green pounds (or about 44 dry pounds) will be required per gallon of FGE produced (MultiTech, 1982, pp. 4-10, 4-11). Plant capacity recommendations specific to each of the study sites are discussed below.

- Lincoln Study Area

  The Milestone 1 Report presented an annual production estimate of 29,442 green tpy of timber residue within 25 miles of Lincoln. This tonnage is equivalent to approximately 775,000 gpy of FGE (MultiTech, 1983). The wood fiber waste of approximately 4,771 tpy could produce approximately 125,500 gpy of FGE. Thus, it is recommended that DNRC consider an FGE with a 900,500 gpy capacity. This value should be treated cautiously, however, as it does not fully incorporate the respective uncertainties in the various estimates of residue availability. For example, if the facility was subsisting on timber residue alone, and the annual average estimate is indeed 30 percent too great, plant capacity would shrink to 542,500 gpy. On another hand, if the facility uses timber and waste residues, and if the above estimates are found deficient by 30 and 55 percent, respectively, the plant capacity expands to about 1,202,000 gpy. An arithmetic average of the "pessimistic" and "optimistic" estimates yields a value of approximately 872,250 gpy, generally in-line with the plant capacity recommended above.

- Livingston Area

The Milestone 1 Report presents an annual production estimate of 7,200 green tpy of "in-woods" residues within a 25 miles of Livingston. This tonnage is equivalent to about 189,500 gpy of FGE (MultiTech, 1983). The wood waste residue estimate of about 5,686 tpy could produce approximately 149,600 gpy of FGE. A summation of the two major feedstock types generates a figure of approximately 339,100 gpy. By repeating the same process as used for the Lincoln site, the "pessimistic" and "optimistic" estimates of annual FGE production are 132,650 gpy and about 478,200 gpy, respectively. The arithmetic mean of these two values is about 305,400 gpy, which is generally in-line with the plant capacity figure recommended above.

3.0 SUMMARY OF VOLUME III: PLANT SCALING AND COSTS

Volume III was prepared from Milestones 3 and 5. Milestone 3 was concerned with plant scaling and costing, while Milestone 5 concentrated on an economic analysis of plant costs compared to potential revenues.

3.1 PLANT SCALING AND COSTING

3.1.1 Objectives

The Milestone 3 Report was prepared with the objective of compiling and estimating the non-site-specific economic factors of making ethanol from wood for plants with capacities (in millions of gallons of ethanol per year) of 2.5, 1.25, 0.775, and 0.2.

3.1.2 Summary

Flow diagrams with material and energy balances were prepared for the Wood-Waste-to-Fuel-Ethanol process plants. The basic process is a Modified Madison Wood process which was submitted in June 1982 (DNRC). Ethanol plant cost estimates are presented herein for these designated capacities:

Capacity (million gpy ethanol/year)	Estimated Cost
0.2	$ 3,119,000
0.775	$ 5,763,000
1.25	$ 7,010,000
2.50	$10,264,000

These cost estimates do not include land purchase and erection of buildings. Actual costs and specific details on sites were considered in Milestone 5 (Economic Analysis) and presented in the Volume III Report.

As the costs indicate, the plant investment per unit of ethanol produced increases substantially with capacity scale-down. Of the sites, the Livingston area has the lowest available wood waste resource and thus would accommodate the smallest capacity plant. It is probable that a waste-straw resource could be developed at Livingston and added to the feedstock with a benefical increase in the economics for this site. Although such efforts are beyond the scope of this project, information previously submitted in a MultiTech proposal relates to this discussion. MultiTech also has a proprietary process for cold embrittlement grinding which could improve the economics of straw processing.

Manpower requirements for the wood-to-ethanol plants have been analyzed and reported in Section 1.5 of Volume III Report. These requirements adversely affect scale-down economics.

3.1.3 Conclusions

Fuel

Increasing the production capacity of fuel alcohol plants can improve the economics of relatively small-scale plants. This may be accomplished by integrating feedstocks with forest and sawmill residues. Further consideration of these additional feedstocks is suggested for any planned facilities.

* Straw

In Montana, straw has ethanol production possibilities. It appears possible to integrate straw with wood waste to make FGE.

The economic value and practicality of using straw for ethanol production may be increased by fine pulverizing, which could permit continuous processing rather than batch processing.

To assist with pulverizing, the cooling of materials with liquid gases embrittles those materials that are not readily grindable by conventional means. MultiTech has a feasible method for using carbon dioxide at -110°F; this requires less than one hp per standard ton of refrigeration. Embrittlement of straw should be adequate in this temperature range.

* Grain

Grain may also be integrated for improved economics.

Equipment

Economic feasibility may be improved by using second-hand equipment, if it is available. This procedure could significantly reduce plant capital costs, particularly in the smaller capacity plants. The impact of equipment substituted is detailed in Milestone 5 on Economics.

3.2 ECONOMIC ANALYSIS

3.2.1 Objectives

The primary objective of Milestone 5 was to analyze economic factors that influenced the cost of product and economic viability for plants located at Anaconda, Livingston, and Lincoln, Montana. Four plant capacities were specifically analyzed and tabulated.

3.2.2 Summary

The objective of the Milestone 5 task was to evaluate the economics (i.e., cost of plant development vs. total revenue) of the manufacture of FGE from wood wastes at Lincoln, Livingston, and Anaconda. Specific costs for the four plant capacities of 200,000, 775,000, 1,250,000, and 2,500,000 FGE gpy were calculated, tabulated, and resolved into graphic presentations. Interpolation of other sizes can be accomplished from the data and figures presented in the Milestone 5 Report.

Economic feasibility can be conveniently measured by determining the length of time required for investment recovery. For the sites and plant capacities being considered, the 2.5 Mgpy plant has payback periods ranging from three years for wood wastes at $20/ton to eight years at $30/ton. The 1.25 Mgpy plant has payback periods of six or seven years, depending on the site, for wood cost of $20/ton. Smaller plants were not economically feasible within the study guidelines.

As plant size increases, the cost of development (capital and interest) is reduced advantageously. Also, the cost of labor (operation and administration) is proportionately less expensive for a larger operation. Significant components of plant costs for all of the plant sizes were the material input costs (primarily wood), capital costs, and interest payments. Major reductions in these components, along with reduced labor costs, would be necessary to make the 0.200 Mgpy plant competitive. In general, the capital and interest components were supplanted by the material inputs as the primary cost factors as plant size increased. Consequently, efforts to reduce wood waste costs, as well as obtaining lower interest rates, would be well rewarded in increased profitability. Another area of good economic return, probably an obvious one, is to lower the initial investment or capital costs.

One method is to purchase used equipment rather than new. In Milestone No. 3, it was assumed that all of the equipment would be purchased new. Obsolescence of chemical plants during the past 25 years and an aggressive salvage industry has created a source of used process equipment that works as well as new. A substantial proportion of the process equipment is not product-specific, and used components are available at 5% to 30% of new prices. Based on an analysis of the equipment list and tabulation of equipment generally available in the used equipment market and typical prices, savings of 26% to 36% of the total plant cost are probable. Consequently, in this economic analysis, used-equipment prices were used as appropriate. Lower feedstock prices would also offer significant cost benefits. Innovative methods of lowering haul costs, such as specialized trailers to increase hauling capacity, should be evaluated carefully. Additionally, other supplemental feedstocks, such as waste straw, should be considered as they could

1) increase potential production capacity, thereby increasing profitability, 2) possibly lower the cost per ton of the feedstock, and 3) provide increased security of fuel supply. One possible source for another type of feedstock at the Anaconda site is the grain terminal in Butte.

Revenue, in 1984 dollars and without the State of Montana incentive payment, is calculated to be $2.21 per gallon of FGE. No credits were taken for plant waste products that possibly could be sold, although credit was taken for other process products, namely methanol, furfural, and syrup.

The requirements for profitable operation of a FGE plant based on wood waste, as shown by this study, are generally this: used equipment should be purchased where possible, loan interest should be 14% or less, wood costs should be below $30/ton and preferably around $20/ton, plant capacity should be at least 1.25 Mgpy, supplemental feedstocks should be used where available, and the FGE plant should be integrated with other manufacturing processes such as livestock feeding with process residues.

3.2.3 Conclusions

The primary conclusions to be reached on the economic feasibility of producing fuel-grade ethanol (FGE) from wood waste are the following:

1. Within the design details available in a feasibility study, and within the constraints mentioned in Section 3.0 of Milestone 5, the largest plant size of 2.5 Mgpy appears economically feasible over a range of wood costs. The next plant size of 1.25 Mgpy possibly

could be economically viable at a wood cost of $20 per ton, but not with higher wood costs. Smaller plants are not economically feasible. Figures 3-1 and 3-2 are a graphic presentation of these relationships.

2. As expected, plant economics are most sensitive to the cost of money and the cost of wood waste. Table 3-1 shows the contribution of the various cost components to the final price for the four plant sizes.

3. Plant capital requirements are a function of the plant size considered, and the degree that used equipment can be obtained. Capital costs can be reduced 26% to 36% with used equipment, with the larger plants showing 7% to 10% more benefit than the 0.2 Mgpy plant.

4. For the three larger plants considered in this study, the operating costs (other than wood) are not a significant cost on a unit of product basis. Particularly the material input costs do not vary appreciably.

   The manpower and administrative services portion of the operating costs does vary proportionately with plant size, going from $1.35 per gallon for the 0.2 Mgpy plant to $.14 per gallon for the 2.5 Mgpy plant.

5. Product value, not including solid waste for animal feed, is $2.21 per gallon of FGE. This number does not include the state incentive

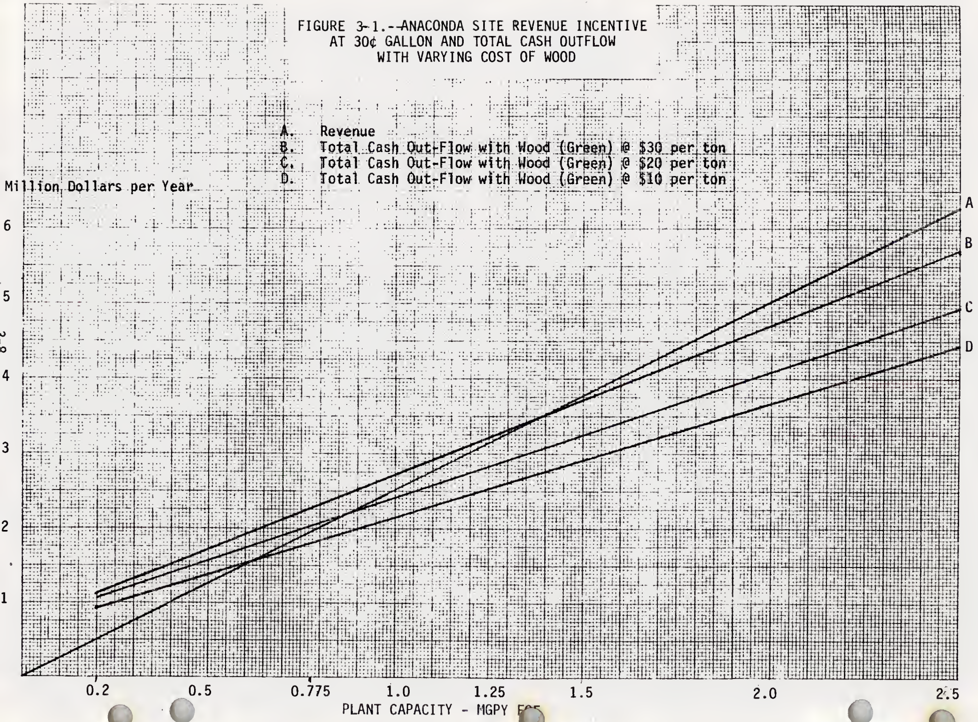

FIGURE 3-1.--ANACONDA SITE REVENUE INCENTIVE AT 30¢ GALLON AND TOTAL CASH OUTFLOW WITH VARYING COST OF WOOD

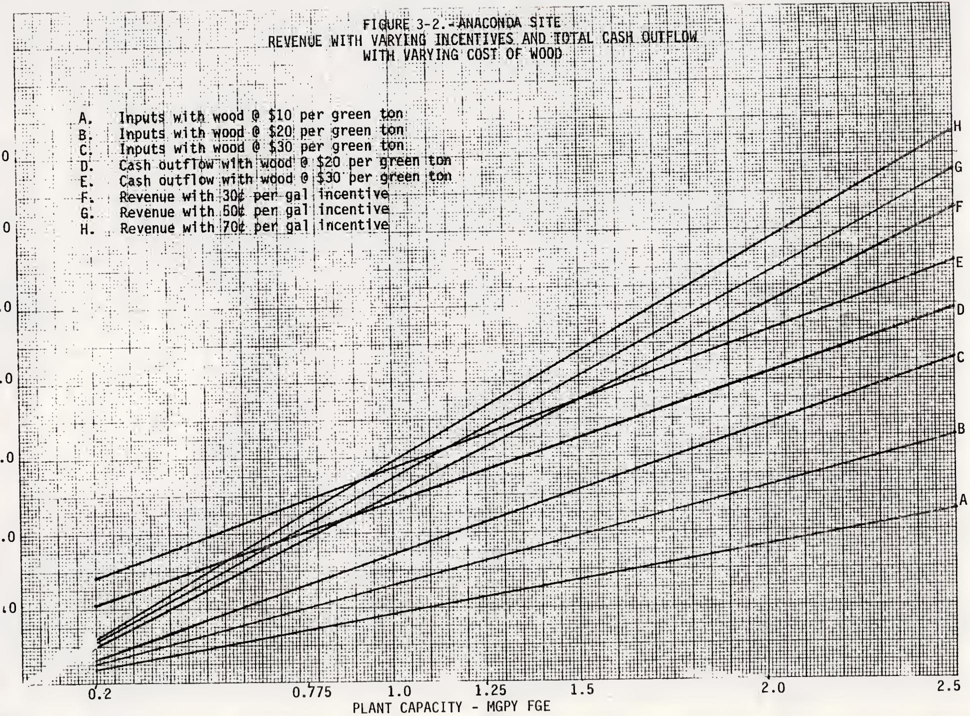

FIGURE 3-2.—ANACONDA SITE
REVENUE WITH VARYING INCENTIVES AND TOTAL CASH OUTFLOW
WITH VARYING COST OF WOOD

TABLE 3-1.--REVENUE AND COST COMPONENTS ON A UNIT PRICE BASIS

	Plant Size, Mgpy FGE			
Cost Component, $	0.2	0.775	1.25	2.5
Material Inputs (excluding wood)*	0.60	0.52	0.51	0.50
Wood @ $20/ton	0.81	0.81	0.80	0.80
Manpower & Administrative Services	1.35	0.35	0.22	0.14
Working Capital	0.08	0.05	0.05	0.05
Insurance & Local Taxes	0.34	0.15	0.11	0.08
Principal Repayment (10 years)	1.15	0.50	0.36	0.26
Loan Interest (14%)	1.47	0.60	0.44	0.32
Total, $	5.80	2.98	2.49	2.15
Revenue (with $.30 incentive)	2.51	2.51	2.51	2.51

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* Costs are for the Anaconda site, the Lincoln and Livingston sites are $.02 to $.03 less.

payment, but it does include the value of the ethanol, methanol, furfural, and syrup products.

6. An obvious method of increasing the likelihood of a successful project is to lower the cost of wood wastes. This would increase the possibility of smaller plants being economically feasible and increase the margin of profitability of the larger plants. One method of lowering wood costs is to lower haul costs. The advantage of lower haul costs would be seen in lower wood costs, which could increase the profitability of small plants.

   One method of decreasing haul costs is to increase haul capacity. The standard hauling trailer can carry 65 cubic yards of material, or only 18 tons of wood waste (3.6 cubic yards per ton). Specially designed trailers should be able to haul at least 60 tons of wood waste, thereby reducing transportation costs from 11¢/ton/mile to 3.5¢/ton/mile. Obviously the profitable haul distance can be increased three- or four-fold. Contracting with the truck tractor and driver to haul the alcohol company's trailer is probably the most economic strategy.

7. Alternate feed stocks, such as straw, should be considered in conjunction with the use of wood wastes. This feed probably would not be lower in cost than wood, but could increase the feasible plant capacity. The best possibility of using straw waste effectively is in the Livingston area, which could probably support a 5.0 Mgpy FGE plant. Marc Montgomery, Livingston Chamber of Commerce, indicated

that Park County alone could probably supply enough straw for a 2.0 Mgpy FGE plant.

A plant in Anaconda designed to produce 2.5 Mgpy FGE from wood waste could ensure fuel supply and enhance economics by using off-grade grain from the grain terminal at Butte.

8. Integration of the ethanol plant into an agricultural complex could improve economic conditions, particularly through shared manpower and administrative services, and possibly through a reduction in the interest rates available. An area group has been investigating the placement of an integrated plant at the Arbiter Plant in Anaconda.

4.0 SUMMARY OF VOLUME IV: ENVIRONMENTAL CONCERNS AND PERMITTING

Volume IV is based on information from Milestone 4 which concentrated on environmental concerns and permitting requirements for an FGE plant at the potential sites.

4.1 OBJECTIVES

The Milestone 4 Report was prepared with the objective of defining preliminary environmental and regulatory planning requirements for the largest feasible FGE plant size in each of the three areas. Agencies, procedures, and standards were identified in obtaining the necessary permits and licenses. Environmental impacts and possible remedial measures to mitigate those impacts were discussed.

4.2 SUMMARY

Initially, the conceptual design was evaluated for probable daily emission rates of atmospheric contaminants, liquid effluents, and solid wastes. These estimates, based upon a composite review and synthesis of the literature, were used to prepare generic impact assessments. "Generic" is an appropriate term, given that process design, capacity, and exact location have not been finalized. Thus, identification of detailed impacts and resource values of special concern must precede completion of formal siting/engineering studies.

All of the unavoidable impacts identified are common to any proposed industrial activity. These impacts include an irretrievable commitment of natural and human resources, localized degradation of air and water qualities, and generation of solid wastes. Again, the significance of these impacts is generally site-specific and cannot be quantified for the various sites at present. Nevertheless, the following general conclusions can be drawn:

- The steam plant operations, as presently envisioned, will cause the facility complex to be designated a "major source" of particulate and SO_2 emissions. Thus, conventional--or possibly innovative--control systems must be designed into the plant during the detailed engineering phase.

- The 2.5 Mgpy operations will not generate environmentally significant concentrations of toxic substances (i.e., priority pollutants). However, on-site wastewater treatment will be required prior to (off-site) disposal. Since EPA has not yet developed effluent guidelines for ethanol plants, the degree of treatment must comply with pollutant-specific regulations enforced by the State of Montana. Fortunately, there are package treatment systems that can bring effluent into compliance with such regulations.

- The solid wastes generated by FGE production are designated under the Resource Conservation Recovery Act (RCRA) as being non-hazardous. Furthermore, EPA has decided not to propose solid waste regulations specific to alcohol fuels plants. Therefore, conventional waste handling/disposal practices will be adequate for solid waste control.

- Sound engineering design, integrated with environmentally conscious siting and operation of the proposed facility, will result in economic benefits far outweighing cumulative environmental detriments.

Federal, state, and county regulatory review authority and licensing/permitting procedures are discussed in the concluding sections of the Milestone 4 Report and Volume IV. Completion of many of these permit applications are predicated upon information not presently known (or available). Thus, time and cost estimates for their preparation are based on previous permitting experience with similar technologies.

4.3 CONCLUSIONS

No major environmental problems are presented by a wood-to-alcohol (FGE) plant. The proper disposal of liquid wastes, primarily waste water and solid wastes must be arranged. Air pollution emissions are those normally associated with any coal-fired steam plant and, therefore, can be conventionally controlled.

The permitting period would be extensive and sufficient time must be allotted for this purpose in the project schedule. Proper design and operation will make an FGE production plant an environmentally acceptable industry.

DNRC 451-811,
AMENDMENT NO. 6

FUEL GRADE ETHANOL PRODUCTION USING WOOD WASTE (RESIDUES) AT SELECTED SITES IN MONTANA

FEASIBILITY STUDY - FINAL REPORT
VOLUME II: RESOURCE AVAILABILITY

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1.0 TIMBER HARVEST RESIDUE STUDY

1.1 INTRODUCTION AND DEFINITIONS

The Milestone 1 Report was prepared with three major objectives in mind. The first objective was to inventory the post timber harvest wood wastes potentially available within 50 miles of the Lincoln and Livingston sites. Included in this inventory is the general characterization of the location, quantity, and physical characteristics (e.g., number and average volume of residue pieces per acre) of the timber harvest residues present in each area. The second objective involved the input of the above data along with estimated residue gathering and transportation costs (to the given FGE facility) into particular economic models. Such modelling results allow determination of a haul distance within which the residues are economically harvestable. The third objective was to adjust the biomass inventory estimates to reflect competition from other users and various environmental attributes which affect the magnitude of the resource base.

Forest residues of value for FGE feedstock include those resulting from forest growth and management activities and logging residues resulting from timber harvesting. The forest residues include natural mortality losses (e.g., due to insect infestation, fires, severe storms); unmarketable trees culled from commercial forest stands (i.e., land capable of growing at least 20 ft^3/acre or producing at least 0.3 ton of biomass/acre/year); and noncommercial or surplus timber stands composed largely of overmature, standing dead or diseased "junk" timber in need of thinning to optimize timber productivity.

Logging residues include trunks over seven feet long and two inches in diameter which cannot be profitably harvested for lumber. All of the wood remaining on the ground after harvest is also classified as logging residue (Keegan and White, 1979). The latter category includes branches and foliage, rejected portions of the cut trunks, and understory vegetation, which is collectively termed "slash."

1.2 METHODOLOGIES

1.2.1 Methodological Overview

The essential purpose of the Milestone 1 study was to determine the largest-scale FGE facility that could be supported by each area's timber harvest residue base. The operating scale will be affected by present and anticipated (future) economic competition for the residue materials. Clearly, the combined costs of residue harvest/transport/handling incurred by the FGE facility cannot exceed the maximum price paid by those operations competing for them. This ceiling price will dictate the distance that residues can be hauled, which determines the volume of residue available for FGE feedstock.

The study, conducted in three phases, includes: 1) a general characterization of the resource base within 50 miles of each site; 2) an economic assessment of the feasibility of residue gathering, including an assessment of competing residue and land uses; and 3) determination of average annual residue available for FGE production.

Presumably, the economic feasibility of FGE production increases when the facilities are relatively larger. To benefit from such "economies-of-scale" it is advantageous to determine the maximum amount of fermentable wood fiber available. The inventory of residues arising from wood milling and fiber recycling operations is discussed in the Milestone 2 Report.

An estimate of average annual residue supply for FGE production can be determined through application of the following resource availability formula, as modified from Tillman (1978):

$$R_E = \Sigma \ [(R_p + R_S) - R_U] - R_M$$

The terms used in this expression are defined as follows:

- R_E represents residues available for FGE productions;
- R_p represents residues generated by the primary forest industry, including those produced by forest growth and mortality, forest management practices, timber harvest, and forest products manufacturing;
- R_S represents residues generated by secondary wood and wood fiber recovery and recycling activities;
- R_U represents residue that appears to be uneconomic to harvest and use; and
- R_M represents residues designated for other purposes, including pulp and paper production, particle and composition board production, in-plant steam/electricity generation, and residential heating.

Given a feedstock supply within a defined study area, more detailed economic feasibility analyses can be performed. Such results indicate the relative cost-competitiveness of using residue for FGE production rather than other potential end-uses.

It must be recognized that specific point or confidence interval estimates of resource quantity are difficult to generate. Estimation difficulty is based on the following facts:

- R_P reflects regional economic variables (e.g., fluctuating demand for raw timber and finished wood products) plus site-specific forest growth rates and changing growth/silvicultural management variables;
- R_S reflects market incentives for widespread collection, concentration, and delivery to the ethanol facility;
- R_U is subject to varying environmental constraints (e.g., steep terrain having highly erodible soils), ease of site access and harvest/yarding/haulage costs; and
- R_M is correlated with those regional economic variables that also influence R_P, plus market incentives for substitution of wood for more conventional fossil fuels for energy production and space heating.

Thus, ultimate availability of the resource base will vary over time, being a function of the selected geographic area and assumptions made regarding the various terms in the above formula. The ultimate economic availability will occur when there is no more profitable use of residue than FGE production.

1.2.2 Residue Inventory

1.2.2.1 General Procedures

Initially, the approximate acreage and ownership pattern of commercial timber lands (CTLs) within 50 miles of each site was determined. This approach ignores the residue supply potentially contributed from the harvest of non-commercial timber stands. However, by focusing on the CTLs (i.e., those lands most likely harvested over time), a conservative estimate of the residue resource base can be determined.

The correlation of the amount of CTL managed by various owners was accomplished via joint use of published land cover type and land ownership maps. County-wide existing Land Use maps (1:126,720 scale) were acquired either from MultiTech files or from the Economic and Community Development Division of the Montana Department of Commerce, Helena. The ownership pattern was determined with Bureau of Land Management (BLM) Mineral and/or Surface Management Status maps (1:100,000 scale) or Natural Resource (Public) Lands in Montana maps (about 1:168,981 scale).

The CTL information contained on the land cover type maps was transferred onto the BLM land ownership maps. In general, the CTL boundaries were sketched for map sections (1 X 1 mile) within 25 miles of the particular site. For sections extending out to 50 miles, an estimate of CTL areal extent was recorded to the nearest one-quarter (and sometimes to the eighth) of a section. A comparison of results between this approach and published values (when available) indicates agreement within 10 to 15 percent.

The next step was to determine the various forest cover types surrounding each site via cursory literature review and personal contacts with local land management personnel. Of particular use were forest-wide planning and resource inventory documents published by the U.S. Forest Service.

Site-specific details for the Lincoln and Livingston areas are discussed in the following section.

1.2.2.2 Site-Specific Procedures

- Lincoln Study Area

  A total of 12 Mineral and/or Surface Management Status quadrangle sheets were used to form the base map. The names and arrangement of these sheets are shown in Figure 1-1, Part A.

  The Existing Land Use sheets for the 10 counties of interest were used in transferring CTL data onto the BLM ownership (base) map. The names and approximate arrangement of the land use sheets are shown in Figure 1-1, Part B.

  Once the CTL-ownership pattern was established, approximate boundaries of the major forest cover types were sketched in. The primary reference for those areas west of the continental divide was a cooperative study prepared by the USDA Soil Conservation Service and Montana Department of Natural Resources and Conservation (1977). This reference presents existing forest cover rather than potential vegetation. For areas east of the continental divide, existing forest types were determined

PART A: BLM LAND OWNERSHIP MAPS AND RESPECTIVE PUBLICATION DATES

Swan Peak, Mt. 1978	Choteau, Mt. 1975	Great Falls North, Mt. 1976
Seeley Lake, Mt. 1979	Dearborn River, Mt. 1975	Great Falls South, Mt. 1976
Missoula East, Mt. 1978	Elliston, Mt. 1975	Canyon Ferry, Mt. 1975
Philipsburg, Mt. 1976	Butte North, Mt. 1975	Townsend, Mt. 1976

PART B: COUNTY-WIDE LAND USE MAPS AND RESPECTIVE PUBLICATION DATES

	Flathead 1981	Teton 1978	
Missoula 1979	Powell 1979	Lewis and Clark No Date	Cascade 1978
Granite 1980	Deer Lodge 1979	Jefferson 1981	Broadwater 1979

FIGURE 1-1.--GRAPHICAL SUMMARY OF THE BLM LAND OWNERSHIP AND EXISTING LAND USE MAPS UTILIZED FOR THE LINCOLN AREA TIMBER HARVEST RESIDUE INVENTORY STUDY

using the Headwaters RC and D Project Plan (1974) where possible. The information in this latter document was supplemented by review of habitat type maps (e.g., Arno, 1979; Ross and Hunter, 1976), the Helena National Forest Multiple-Use Plan (USDA, Forest Service, 1972b), and field observations made previously by the author. Completion of the forest cover type mapping allowed estimation of the relative proportion each tree species or species association may contribute to the overall harvest residue (resource) base. Furthermore, use of published residue per acre by cover type values allows estimation of green tonnage production potential within the 50-mile study area.

All reference materials and working maps used in determining CTLs within the defined study area are on file at MultiTech's Environmental Department.

- Livingston Study Area

A total of six Public Lands in Montana quadrangle sheets were used to form the base map. The names and arrangement of these sheets are shown in Figure 1-2, Part A.

The Existing Land Use sheets for the eight counties of interest were used in transferring CTL data onto the BLM ownership (base) map. The names and approximate arrangement of the land cover type sheets are shown in Figure 1-2, Part B. All reference materials and working maps used in determining CTLs are on file at MultiTech's Environmental Department.

PART A: BLM LAND OWNERSHIP MAPS AND RESPECTIVE PUBLICATION DATES

Townsend, 23 1980	Castles, 24 1981	Snowy, 25 1981
Madison, 33 1980	Park, 34 1975	Beartooth, 35 1978

PART B: COUNTY-WIDE LAND USE MAPS AND RESPECTIVE PUBLICATION DATES

Broadwater 1979	Meagher 1981	Wheatland 1981

Madison 1981	Gallatin 1981	Park 1979	Sweet Grass 1981	Stillwater 1981

FIGURE 1-2.--GRAPHIC SUMMARY OF THE BLM LAND OWNERSHIP AND EXISTING LAND USE MAPS UTILIZED FOR THE LIVINGSTON AREA TIMBER HARVEST RESIDUE INVENTORY STUDY

Three major references were used to estimate the relative proportions of major commercial forest types present within the study area. These sources include the Gallatin National Forest Multiple-Use Plan, Part I (USDA, Forest Service, 1972a), area-wide timber resource statistics (Felt and Barrett, 1979), and selected habitat-type documents (e.g., Arno, 1979; Ross and Hunter, 1976). These data were supplemented with field observations made previously by the author.

1.2.3 Economic Analysis of Residue Gathering and Transportation Activities

1.2.3.1 General Procedures

Two models were used in estimating the economically feasible haul distance (harvest and transport) for moving residue to each FGE plant. The first model used was the USDA Northern Rocky Mountain Zone average timber appraisal cost approach, as adjusted for assumed variability in each study area's harvest/transport conditions (USDA, National Forest Service, 1977). The second model was one developed by Dr. Richard Withycombe for estimating costs of collecting and transporting forest residues within the Northern Rocky Mountain region (Withycombe, 1980). In order to "run" these models, a number of characteristics specific to each forest cover type and general timber harvest/transport parameters must be as well qualified as possible. These data needs are outlined below.

For each major forest cover type, the mean value and range (in values) were defined for the following variables: 1) diameter at breast height (dbh); 2) number of trees present per acre; 3) merchantable biomass produced per acre, expressed in both board feet and cubic feet acre^{-1}; and 4) both volume (inherent or arithmetic assumptions) and scaling (internal consistencies) defects. In regard to commercial timber harvest practices, assumptions were made as to: 1) the mean and range in percent slope upon which harvest and skidding occurs; 2) types of vehicles used in skidding; and 3) storage distances to the loading area. Additional details pertinent to the individual site areas are discussed below.

1.2.3.2 Site-Specific Procedures

- Lincoln Study Area

  The primary sources of information came from personal interviews and/or phone contacts made with forest management personnel in federal agencies. The three major sources were: 1) USDI, BLM District (Butte) and Garnet Resource Area (Missoula) Offices; 2) Supervisor's (Helena) and District (Lincoln) Offices of the Helena National Forest; and 3) Seeley Lake District Office of the Lolo National Forest. Additional sources of information included correspondence with particular individuals and review of various timber management plans prepared by the above agencies.

- Livingston Study Area

  The major sources of information came from personal interviews and/or phone contacts made with personnel from the Gallatin National Forest Supervisor's Office in Bozeman. Additional information was acquired by reviewing published timber resource statistical and multiple-use planning documents for the Gallatin National Forest.

1.3 STUDY RESULTS

1.3.1 Lincoln Study Area

1.3.1.1 General Characterization of the Forest/Residue Resource Base

Initially, it was decided that CTLs present within 50 miles of Lincoln could be grouped into four major cover types. The predominant species-associations and their estimated proportions (in decimal form) within the study area are as follows: 1) Ponderosa pine-Douglas fir/bunchgrass on warm/dry sites, 0.15; 2) Douglas fir-lodgepole pine on cool/dry sites, 0.55; 3) lodgepole pine-subalpine fir on cool/moist sites, 0.27; and 4) "bottomland" (generally warm/moist) sites dominated by Engelmann spruce, grand fir, and western larch, 0.03. Furthermore, the species harvest distribution (on a species-by-acre basis) was assumed to be 0.55, 0.40, 0.05, respectively for lodgepole pine, Douglas fir, and "other" species.

The above estimates were arrived at with the literature references cited in Subsection 2.2.2.1, plus the multiple use plan prepared for the Lolo National Forest's Gold Creek Planning Unit (USDA, Lolo National Forest, 1974). Personal contacts included: Messrs. Steve O'Brien (October 28, 1982) and Lace Smith (March 21, 1983) of the Lincoln District Office, Helena National Forest; Mr. Kent Nelson (March 16, 1983) of the Supervisor's Office, Helena National Forest; Messrs. Dick Betts (March 21, 1983) and Henry Koch (March 22, 1983) of the Garnet Resource Area Office, BLM, Missoula; Mr. Bill Torgersen (March 23, 1983) of the BLM District Office, Butte; and Mr. Boyd Gossard (March 21, 1983) of the Seeley Lake District Office, Lolo National Forest.

It was assumed that areas subject to timber/residue harvests would be either even-aged lodgepole pine stands or uneven-aged mixed conifer stands. It also was assumed that species-specific characteristics discussed below are representative of the medium-to-overstocked CTLs in the study area.

The following assumptions are applicable for sites dominated by lodgepole pine:

- About 68 percent of the total acreage occupied by this species has trees averaging from 2.7 to 5.7 inches diameter at breast height (dbh), with a range from 0.1 to about 18.0 inches;
- The number of total trees per acre ranges from around 562 on commercial stands (e.g., suitable for post/pole and saw timber harvest) to 3000 or more in "doghair" stands (i.e., dbh <2.5 inches). The number of stems, constituting growing stock plus ground-rot and cull trees, ranges from 250 to over 1860 per acre;
- Production of merchantable biomass varies from 350 to 8500 board feet, Scribner-Decimal C scale. This range is based on gross volume estimates for a variable-top utilization scheme; that is, cutting at a given height regardless of the diameter at that point. In such a case, each tree would be cut at the point where the diameter is about 40 percent of the dbh. For those stands allowing harvest of logs 5 inches in diameter at the top, the gross volume increases to a range of 400 to 13,500 board feet. In this latter case, gross cubic feet volumes per acre would range from 125 to 3860; and
- A harvest volume defect (estimated error) of 5 to 8 percent exists in merchantable trees.

For sites dominated by Douglas fir, the following assumptions are applicable:

- About 68 percent of the total acreage occupied by this species has trees averaging from 4.1 to 8.5 inches dbh, while dbh ranges from 0.1 (tip diameter) to about 28.5 inches;
- The number of total stems per acre ranges from around 180 to 1380 on commercial stands. The number of stems constituting growing stock plus sound rot and cull trees ranges from 114 to over 1000 per acre;
- Production of merchantable biomass varies from 500 to 11,500 board feet, Scribner-Decimal C scale. For stands allowing harvest to a 5-inch top, the gross volume increases to a range from 1000 to over 18,000 board feet. In this latter case, gross cubic feet volumes per acre would range from 315 to 5140; and
- A harvested volume defect of 8 to 10 percent exists.

In regard to commercial timber harvest practices, it was assumed that:

- Percent slope ranges from approximately 0 to over 60, but averages nearer to 25 to 30;
- Ground skidding usually is done with medium-weight tracked or rubber-tired vehicles;
- Yarding distances commonly vary in the range from 1000 to 1200 feet, and rarely exceed 1500 feet; and
- Forest-wide, multi-species scaling defects range from 6 to 12 percent but average 8 percent.

Following from the first assumption (regarding slope characteristics), two additional assumptions were made:

- At present, most timber harvest is done by hand falling, although mechanical methods are used occasionally. On slopes greater than 40 percent, cable ground logging methods are practiced, which will become more prominent in the future.
- "Tractor ground" logging would lend itself to in-woods chipping of the residue; on cable system harvests, the materials may have to be trucked a short distance, within the sales boundary, prior to reaching a flat landing where they could be chipped.

Table 1-1 summarizes the representative number of pieces and equivalent biomass estimates by harvest component for mature stands of the various forest cover types present within the study area. The volume estimates were derived by multiplying cubic feet per acre values specific to each forest cover type (Benson and Schlieter, 1980, Table 2) by the estimated acreage of each cover type. The number of pieces per component estimates were extrapolated from Tables 3 and 4 in Benson and Schlieter (1980) and Tables 4 and 9 in Brown _et al_ (1977).

Table 1-1 indicates that an average acre of representative CTL land contains about 4,173 cubic feet (cf) of harvestable biomass. These quantites assume clearcutting practices close to utilization standards. Close utilization of the woody biomass will gather at least the amount of material per acre that would be available if the given area was cut according to conventional utilization practices, (Benson and Johnston, 1976). This biomass estimate could be easily halved in those situations wherein young, mixed-conifer stands are

TABLE 1-1.--SUMMARY OF NUMBER OF PIECES AND EQUIVALENT BIOMASS ESTIMATES FEASIBLY HARVESTED PER ACRE FOR A MATURE, COMPOSITE, TIMBER STAND PRESENT WITHIN A 50-MILE RADIUS OF LINCOLN, MONTANA

Component		Number of Pieces	Equivalent Biomass (cf per acre)
Green Trees			
Merchantable Logs[a]		385	2,233
Cull[b]		38	223
Tops/Branches/Foliage[c]		385	1,116
Small Stems[d]		100	17
	Subtotal	908	3,589
Standing Dead[e]		96	384
Down Dead[f]		100	200
	Grand Total	1,104	4,173 [g]

Notes:

a) Assumes a weighted average dbh of 7.5 inches, an average merchantable tree length of 24 ft., and an average total tree height of 32 ft; also assumes an average volume of 5.8 cf per merchantable section and about 8.7 cf for "full tree" volume.

b) Assumes a harvest volume defect of 10 percent and a 9:1 ratio between merchantable pieces and cull pieces.

c) From note a), assumes (8.7 - 5.8) = 2.9 cf per top/branches/foliage unit.

d) Assumes average dbh and tip diameter of 2.0 and 0.1 inches, respectively and average (total) height of 8 ft; volume calculated using Smalian's Rule (Withycombe, 1980, Table 10), resulting in an average value of 0.17 cf (including stem and foliage).

e) Extrapolated from BLM stratified sampling plot data acquired within the Garnet Resource Area; assumes a growing stock: standing dead/sound trees of about 3:1. Presumes lengths ranging from 7 to 32 ft, dbh $\geq$ 2.5 inches, and average volume of 4.0 cf; this volume does not include crumbly rot.

f) Piece number extrapolated from Table 3 in Benson and Schlieter, 1980. Presumes lengths $\geq$ 7 ft. and average volume of 2.0 cf.

g) Using a weighted average wood density of 27.4 lbs per ft^3 (Brown, et al., 1977, Table 9), this cf $acre^{-1}$ volume is equivalent to approximately 57.2 tons $acre^{-1}$.

thinned using conventional utilization standards (MultiTech, 1982, p. 4-15). For purposes of this study, clearcutting to close utilization standards was chosen as it optimizes harvest efficiency and cost-effectiveness; the matter of cost-effectiveness is discussed below.

The above harvestable biomass values assume that a sufficient amount per acre of woody residues will be left upon the site to accomplish the following:

- Not interfere adversely with ectomycorrhizal/nutrient cycling activity (Brown and See, 1981, p. 9);
- Not disrupt future timber productivity, (Pimental et al, 1978); and
- Minimize adverse environmental damage (e.g., sedimentation, soil profile disruptions) and interference with other resource values, e.g., wildlife habitat, (Pimental et al, 1981).

The retrieval of cull materials, tops of submerchantable trees, and a portion of the standing dead trees and down trees using conventional harvest practices is most cost-effective when done concurrently with saw timber logging operations. Additional wood fiber may also be gathered at this time (e.g., slash from old logging sites and dead material on sites not immediately scheduled for logging). However, under economic constraints, the "cost of this additional material could not be any less than logging residue and its value per unit (i.e., per cubic foot) would not be any greater," (Keegan et al, 1981, p. 6). Generally these other sources either have higher costs or lower usage potential than logging residues or have ready markets (such as posts); thus, their inclusion in the potential feedstock resource would not improve the profit potential (Keegan et al, 1981, p. 11). It becomes apparent that per unit costs will be minimized and biomass harvest rates and volumes optimized by conducting wood residue gathering in conjunction with commercial timber harvesting operations.

These conservative viewpoints could be modified favorably if federal and state subsidies, such as the following, were in effect:

- Increasing the level of hard money appropriations for contribution of timber access roads, then prorating such investments over the various timber sales subsequently occurring in the given area;
- Offering energy credits on taxes paid by lumber or mineral development companies for upgrading the quality of the road system(s) under their control; this may open up areas of otherwise marginal timber stands; and
- Increasing the incentives for the yarding of unmerchantable materials, if possible.

The economic and political climate required to implement these incentives is uncertain; thus, such advantages cannot be depended upon to cause significant increase in the wood fiber resource base. Again, the reliance on clearly profitable instances of timber harvest is the safest policy, particularly as the study area's national forest system(s) comes under increasingly more regulated management.

The timber and residue haulage assumptions used in the Forest Manual approach to harvest/transport cost estimation were as follows:

- The merchantable timber is cut into 24-foot lengths, each having an average gross merchantable volume of 5.8 cf (Withycombe, 1980, Table 10);

- The usable residues range from 7 to 32 feet long, average 18.2 feet (see Table 3 in Benson and Schlieter, 1980), and possess an average gross volume of 3.0 cf (Table 1-1 and Table 10 in Withycombe, 1980);
- On-highway log trucks having a maximum haulage capacity of 1040 cf and a load limit of 52,000 lbs are used to haul the timber/wood fiber; while,
- Capacity is reduced to 30,000 lbs for pieces averaging less than 10 cf due to "the difficulty of loading many small pieces in a truck" (Withycombe, 1980, p. A-6).

In order to evaluate potential road quality between any given timber harvest area and the FGE facility site, the BLM ownership/CTL (base) map was inspected, along with review of available 1:250,000-scale AMS ("Butte" and "Choteau") quadrangle sheets. From this inspection, the following road types and proportionate availability in the facility area were derived:

- Primary highways with excellent alignment and a slope range of ± 6 percent present on 25% of the area;
- Double-lane secondary roads with a mixture of paved and graveled surfaces and a slope range of ± 8 percent present on 30% of the area;
- Single-lane graveled roads with ditches, fair-to-poor alignment and a slope range of ± 8 percent present on 30% of the area; and
- Single-lane dirt roads without ditches, fair alignment and a slope range of ± 8 percent present on 15% of the area.

1.3.1.2 Determination of the Economically Feasible Residue Harvest and Transport Radius

The first approach towards estimating the economically feasible haul distance used the USDA Northern Rocky Mountain Zone average timber appraisal costs, as adjusted for the assumed variability in harvest site conditions (USDA, National Forest Service, 1977). The results indicate a 1983 felling/limbing cost of $45.24 per thousand board feet (MBF), presumably incorporating variability among the species harvested. Furthermore, the 1983 average skidding cost was calculated to be $47.54 per MBF. The mechanics of these calculations are summarized in Table 1-2. As discussed above, the costs of processing logging residues would be at least as expensive as those incurred for saw timber operations. The two cost estimates above probably represent the upper bound of credibility for saw timber, and may be more applicable to logging residues. The zone average-derived appraisal costs (for saw timber and poles) tend to be greater than costs actually observed within the study area (MultiTech, 1982, p. 4-19), so tend to be on the conservative side of cost estimation. Data pertaining to cost estimations for loading/unloading and transportation of saw timber are given in Table 1-3; this information was combined with data from the previous table to estimate an overall radius of economic feasibility. Table 1-4 presents in detail the means of deriving an estimated one-way haulage distance (radius) of 57.2 miles.

The estimated haul distance of 57.2 miles appeared to be somewhat optimistic, given D.A. Tillman's (1978) discussion of effective transport distance. Tillman states that maximum profitable truck transport of softwood residues (@ 45 percent by weight moisture content) is about 40 miles (Table II, p. 94).

TABLE 1-2.--RATIONALE FOR APPRAISAL OF FELLING/LIMBING AND SKIDDING COSTS VIA USE OF THE USDA FOREST MANUAL (IN 1983 DOLLARS)

FELLING/LIMBING COSTS[a]

Component	Percent Adjustment Factor
Average dbh = 7.5 inches	+ 70.0
Stem density = 481 acre^{-1}	- 2.0
Percent slope = 25-30	+ 2.5
Merchantable tree defect = 8%	- 10.0
TOTAL ADJUSTMENT	+ 60.5

Zone average (excluding rent, lease and depreciation) = \$24.25
Rent, lease and depreciation = \$6.32
Appraisal Cost Estimate: (\$24.25 x 1.605) + \$6.32 = \$45.24 MBF^{-1}

SKIDDING COSTS[b]

Component	Percent Adjustment Factor
Net volume acre^{-1} = 7600 MBF [c]	+ 1.5
Average no. logs per gross MBF^{-1} = 18 [d]	- 15.0
Skidding distance = 1000 ft.	+ 9.0
Scaling defect = 8%	- 1.0
TOTAL ADJUSTMENT	- 5.5

Zone average (excluding rent, lease and depreciation) = \$42.71
Rent, lease and depreciation = \$7.18
Appraisal cost estimate: (\$42.71 x 0.945) + \$7.18 = \$47.54 MBF^{-1}

Notes:

a) Taken from pp. 2422.41--2 and 2422.41--4 in the Manual, FSM 6/81 R-1 Supp 276.

b) Taken from pp. 2422.41--2 and 2422.41--6 in the Manual, FSM 6/81 R-1 Supp 276.

c) From Table 3-1, the total merchantable log volume plus standing dead volume equals 2617 cf; assume average ratio of 3.3 bdft per cf, thus equivalent to 8636 MBF gross volume; the net volume is calculated using a harvest volume defect of 10 percent for merchantable logs and 25 percent for standing dead material.

d) Calculated by dividing gross MBF volume acre^{-1} by merchantable stems acre^{-1}, i.e., 8636 ÷ 481 ≈ 18 stems MBF^{-1}.

TABLE 1-3.--RATIONALE FOR APPRAISING TIMBER LOADING AND HAULAGE COSTS VIA USE OF THE USDA FOREST MANUAL APPROACH

Component	Value Utilized
Gross volume (green tons)[a]	17.25
Loading Time (minutes)[b]	58
Road Quality--see discussion in text	
Averaged Speed (mph)[c]	11.0
Transport Costs	
Fixed daily costs[d]	\$ 70.49
Labor per day[e]	\$208.23
Unloading time (minutes)[f]	45

Notes:

a) Presumably the maximum volume capable of being hauled, given the small lengths and volume-per-piece characteristics of the materials, (see p. 3-7).

b) Extrapolated from Table 2, p. 2422.41--21 in the USDA *Forest Manual* (1977); the weighted value derived from this table was multiplied by 1.5 to adjust for added difficulty in loading these materials.

c) Extrapolated from Table 3, p. 2422.41--23 in the USDA *Forest Manual* (1977); the weighted average mph was calculated as follows: (15.87 x 0.25) + (10.43 x 0.30) + (8.62 x 0.30) + (8.68 x 0.15) ≈ 11.0 mph.

d) Calculated from p.2422.41--18 in the USDA *Forest Manual* (1977); \$17,271 ÷ 245 = \$70.49 per operating day.

e) Calculated from p. 2422.41--18 in the USDA *Forest Manual* (1977), but using a 10-hour work day = \$249.87 x 10/12 = \$208.23 day^{-1}.

f) Author's observations/impressions gained while serving as an employee for the Flathead National Forest Service, summers of 1971-1976.

TABLE 1-4.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAUL DISTANCE, USING THE USDA FOREST MANUAL MODEL (IN 1983 DOLLARS)

CRITICAL ASSUMPTION: The FGE facility must be able to pay up to \$43.60 green ton^{-1}, thus remaining competitive with the anticipated pulpwood/fiber product markets (and possibly with the house log market--see Keegan, 1982).

APPROACH:

1. Assume in-plant chipping and associated handling costs of \$3.82 green ton^{-1} (see Table 4-9 in MultiTech, 1982; adjusted to 1983 dollars via use of a 9 percent inflation of the original 1981 value).

2. Ceiling price per load: 17.25 green tons load^{-1} x \$43.60 green ton^{-1} = \$752.10 load^{-1}.

3. Conversion of MBF to green tons: \$92.78 MBF^{-1} x 1 MBF/1000 BF x (10 lbs/BF)$^{-1}$ x 2000 lbs. ton^{-1}, equivalent to \$18.56 green ton^{-1}. The lbs per bdft conversion was taken from Table II in Withycombe, 1980.

4. Expression for calculating the economically feasible haulage radius:

   a) $\$752.10 = \$320.16 + (1.717 \text{ hrs.} \times \$20.82 \text{ hr.}^{-1}) + \frac{\text{distance (in miles)}}{11.0 \text{ mph}} \times \$20.82 \text{ hr.}^{-1} + \text{distance (miles)} \times \$0.993 \text{ mile}^{-1} + \$65.90$ (for shipping, load^{-1});

   The weighted cost mile^{-1} factor, contained within the brackets, used the Forest Manual's cost mile^{-1} values of 0.5224 and 1.5674 for paved and unpaved roads, respectively (Forest Manual, 1977, p. 2422.41--18). The mechanics of calculating the above factor are as follows:

   [highway driving proportion, 0.25 + double-lane driving proportion, 0.30] x \$0.5224 mile^{-1} + [single-lane gravel road driving proportion, 0.30 + single-lane dirt road driving proportion, 0.15] x \$1.5674 mile^{-1} = \$0.9926 mile^{-1} = \$0.993 mile^{-1}.

   b) \$752.10 - \$320.16 - \$35.75 - \$65.90 = (\$1.893 mile^{-1} + \$0.993 mile^{-1}) = \$2.886 mile^{-1} traveled.

   c) Thus, by dividing the residual price per load by the travel cost per mile, the total miles allowed for travel (and still break even on costs) can be calculated. The results of this calculation are shown below.

   "Haulage allowance" (in miles) = $\frac{\$330.29}{\$2.886 \text{ mile}^{-1}}$ = 114.4 miles round trip.

He continues by noting that comparison of this value "with other studies finds substantial agreement on an approximate 50 mile radius for the movement of wood fuels," (p. 95). Furthermore, one should recall the caveat from the USFS that the Forest Manual calculations are intended for saw timber, not harvest residues. Thus, it is believed that the calculated haul distance represents (and probably exceeds) the maximum economically feasible range.

The R. Withycombe (1980) cost appraisal model was used in the second approach for estimating the economically feasible haul distance. Information used initially in the modelling effort is summarized in Table 1-5. The results, shown in Table 1-6, indicate saw timber and residue can economically be hauled approximately 19.5 and zero miles, respectively. This conclusion assumes break-even economics for both logger and plant operator (i.e., no profit-taking), and no external subsidizing of incurred costs. If the residue materials are chipped at the harvest site, and hauled away in 25-ton capacity chip vans, the feasible haul distance appears to be zero miles regardless of whether residues are debarked before chipping. The mechanics used to derive these estimates are shown in Table 1-7. Given the presence of mountainous terrain with roads presumably having sharp switchbacks, a presumed shortage of level space for chipping operations, and difficult processing economics, the residues should be chipped at the FGE site.

In order to test the sensitivity of the model to changes in the assumed (input) values, it was rerun using more optimistic dbh and cf volume-per-piece estimates. The modifications made to the initially-used values (Table 1-5)

TABLE 1-5.--SUMMARY OF DATA NEEDS FOR INPUT INTO THE R. WITHYCOMBE COST ESTIMATE MODEL (EXPRESSED AS 1983 DOLLARS PER GREEN TON), FIRST ITERATION

Component	Fiber Type Saw Timber[a]	 Logging Residues[b]
Hand felling and limbing costs	8.52	56.24
Grapple skidding costs[c]	4.21 to 9.12[d]	4.21 to 31.64[e]
Loading/hauling costs[f]	7.21	13.32
Unloading Costs[g]	3.80	8.12
∑	$23.74 to $28.65	$81.89 to $109.32

Notes:

a) Assumes an average dbh of 9.0 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

b) Assumes an average dbh of 4.0 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

c) Assumes an average grapple skidding distance of 1000 ft., average saw timber volume of 7.8 cf per 24 foot section, and an average residue volume of 1.0 cf per 18 foot section. Cost estimates are extrapolated from Table 3 in R. Withycombe, 1980.

d) The lower cost follows from the optimistic assumption that each load will have a volume of 150 cf; the higher cost follows from the more conservative assumption that only 10 stems can be carried per load, totalling 78 cf volume.

e) The lower cost follows from an optimistic assumption that each load will have a volume of 150 cf; the higher cost follows from the more conservative assumption that only 20 stems can be carried per load, totalling 20 cf volume.

f) Assumes an average (one-way) haul distance of 25 miles and road conditions similar to those used in the Forest Manual cost appraisals. Cost estimates are extrapolated from Table 5 in R. Withycombe, 1980, using the average volume per piece estimates contained in Note c), above.

g) Assumes same saw timber and residue dbh averages as given in Note c), above. Cost estimates extrapolated from Table 8 in R. Withycombe, 1980.

TABLE 1-6.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAULAGE DISTANCE USING THE WITHYCOMBE MODEL (IN 1983 DOLLARS), FIRST ITERATION

CRITICAL ASSUMPTION: The same as given in Table 1-4 (i.e., a \$43.60 green ton^{-1} price ceiling on as-received residue feedstock).[a]

APPROACH:

1. Assume in-plant chipping and handling costs of \$3.82 per green ton (see Table 1-4).

2. Assume ceiling price per 17.25 ton shipment of \$752.10 (see Table 1-4).

3. Assumed resource costs per green ton: a) an average saw timber cost of \$26.20, and b) an average residue cost of \$95.60 (taken from Table 1-5).

4. Input pertinent values into the same equation form as presented in Table 1-4. The estimate for total haulage distances judged to be economically feasible are as follows: a) for saw timber, 39.0 miles (i.e.,~ 19.5 miles radius) and b) for residues, 0 miles.

Note:

a) The following additional assumptions were utilized in the calculations:

   1) An average speed of 11.0 mph and a tractor/trailer operating cost of \$0.993 mile^{-1};
   2) Loading/unloading times totaled to 1.717 hours; and
   3) A \$37.12 hour^{-1} cost for the log truck and driver (extrapolated from p. A-7 in Withycombe, 1980 and adjusted to 1983 dollars).

TABLE 1-7.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAULAGE DISTANCE FOR FIELD-CHIPPED RESIDUES, USING THE WITHYCOMBE MODEL (IN 1983 DOLLARS)

CRITICAL ASSUMPTION: The same as given in Table 1-4.

APPROACH:

1. From Note 1, Table 6 in Withycombe (1980), assume production costs of \$5.391 per green ton of barked residue and \$4.312 per green ton of unbarked residue. The chipped materials will be hauled about 25 miles to the FGE site in 25-ton capacity chip vans on the same roads traveled otherwise by tractor/trailer logging trucks.

2. Make the following assumptions: a) hand felling-limbing and grapple skidding costs averaging \$74.16 green ton^{-1} (Table 1-5) for debarked feedstock (to the chipper); b) for unbarked feedstock not requiring limbing, assume an average cost of \$55.42 green ton^{-1} (Table 1-5, using two-thirds of the given felling/limbing cost); c) an average speed of 11.0 mph and an operating cost of \$0.950 mile^{-1}; d) loading/unloading time totalling 1.500 hours; and e) labor costs set at \$20.82 hour^{-1} (Table 1-4).

3. Input the pertinent values into the same equation form as presented in Table 1-4. This involves solving the following equation for "d." The first equation is the case for unbarked residue field processing, haulage and on-site (FGE) storage/handling. The second equation is the case for barked residue processing, etc.

Equation 1

$$(\$43.60\ \text{ton}^{-1})(25\ \text{tons}) = (\$55.42)(25) + (\$4.312)(25) + (1.500\ \text{hours} \times \$20.82\ \text{hours}^{-1})$$

$$+\ \frac{\text{distance (in miles)}}{11.0\ \text{mph}} \times \$20.82\ \text{hour}^{-1} + \text{distance (miles)} \times \$0950\ \text{mile}^{-1}$$

$$+\ (\$3.73\ \text{ton}^{-1} \times 25\ \text{tons})\ \text{for FGE chip storage and handling.}$$

$$\$1090.00 = \$1385.50 + \$107.80 + \$31.23 + [1.893d + 0.950d] + \$93.25.$$

$d \leq 0$ miles.

Equation 2

$$\$1090.00 = (\$74.16)(25) + (\$5.391)(25) + \ldots + \$93.25$$

$d \leq 0$ miles

are shown in Table 1-8. The results of the second "run" are shown in Table 1-9. The results indicate economically feasible haul distances for saw timber and residue approximately 32.2 and 11.2 miles, respectively. Given past experience with timber haulage into mills at Lincoln, 30 miles appears reasonable as a maximum economic haul distance, while 19 miles is a reasonable average value.

Overall, the determination of economic haul distance is very sensitive to assumptions pertaining to timber and wood fiber harvesting, transport, and in-plant processing costs. Credible estimates of the economically feasible haul distance for wood residues range from zero to over 50 miles. As the Withycombe model is better designed to evaluate wood residue harvesting costs (than is the Forest Manual method), the arithmetic average of those values generated by both models represents a moderate figure of approximately 22.0 miles (radius). This is not to say that the use of the Forest Manual approach was an exercise in futility; the harvest/hauling of commercial saw timber within 60 or so miles from Lincoln appears to be economically feasible. However, given the magnitude of economic investment (risk) involved in constructing and operating a large ($\geq$ 0.67 million gallon per year) FGE facility, and given the degree of presumed accuracy inherent in the models' parameters, a haul distance approaching or exceeding 50 miles cannot be recommended at this time.

The major topographic and cultural features present within 15 miles of the plant are shown in Figure 1-3.

TABLE 1-8.--SUMMARY OF DATA NEEDS FOR INPUT INTO THE R. WITHYCOMBE COST ESTIMATE MODEL (EXPRESSED AS 1983 DOLLARS PER GREEN TON), SECOND ITERATION

	Fiber Type	
Component	Saw Timber^a	Logging Residues^b
Hand felling and limbing costs	3.96	39.86
Grapple skidding costs^c	4.21 to 5.28^d	6.35 to 6.55^e
Loading/hauling costs^f	7.58	7.76
Unloading Costs^g	4.12	4.28
∑	\$19.87 to \$20.94	\$58.25 to \$58.45

Notes:

a) Assumes an average dbh of 12.5 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

b) Assumes an average dbh of 4.5 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

c) Assumes an average grapple skidding distance of 1000 ft., average saw timber volume of 5.9 cf per 16 foot section, and an average residue volume of 5.0 cf per 18 foot section. Cost estimates are extrapolated from Table 3 in R. Withycombe, 1980.

d) The lower cost follows from the optimistic assumption that each load will have a volume of 150 cf; the higher cost follows from the more conservative assumption that only 10 stems can be carried per load, totalling 125 cf volume.

e) The lower cost follows from an optimistic assumption that each load will have a volume of 100 cf; the higher cost follows from the more conservative assumption that only 20 stems can be carried per load, totalling 90 cf volume.

f) Assumes an average (one-way) haul distance of 25 miles and road conditions similar to those utilized in the Forest Manual cost appraisals. Cost estimates are extrapolated from Table 5 in R. Withycombe, 1980, using the average volume per piece estimates contained in Note c), above.

g) Assumes same saw timber and residue dbh averages as given in Note c), above. Cost estimates extrapolated from Table 8 in R. Withycombe, 1980.

TABLE 1-9.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAULAGE DISTANCE USING THE WITHYCOMBE MODEL (IN 1983 DOLLARS), SECOND ITERATION

CRITICAL ASSUMPTION: The same as given in Table 1-4 (i.e., a \$43.60 green ton^{-1} price ceiling on as-received residue feedstock).[a]

APPROACH:

1. Assume in-plant chipping and handling costs of \$3.82 per green ton (see Table 1-4).

2. Assume ceiling price per 17.25 ton shipment of \$752.10 (see Table 1-4).

3. Assumed resource costs per green ton: a) an average saw timber cost of \$20.40, and b) an average residue cost of \$58.35 (taken from Table 1-5).

4. Input pertinent values into the same equation form as presented in Table 3-4. The estimate for total haulage distances judged to be economically feasible are as follows: a) for saw timber, 64.4 miles (i.e., ~ 32.2 miles radius) and b) for residues, 22.5 miles (i.e., ≈ 11.2 miles radius).

Note:

a) The following additional assumptions were utilized in the calculations:

   1) An average speed of 11.0 mph and a tractor/trailer operating cost of \$0.950 mile^{-1};
   2) Loading/unloading times totaled to 1.500 hours; and
   3) A \$37.12 hour^{-1} cost for the log truck and driver (extrapolated from p. A-7 in Withycombe, 1980 and adjusted to 1983 dollars).

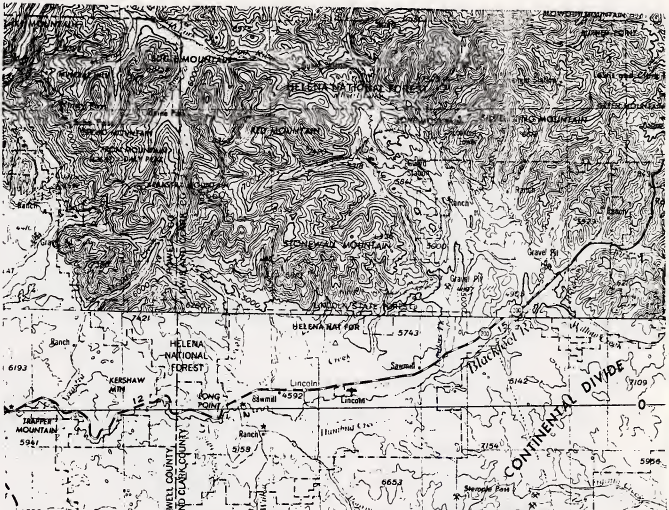

FIGURE 1-3.--RESOURCE STUDY AREA MAP FOR THE LINCOLN FGE SITE.

1.3.1.3 Estimation of the Magnitude of the Residue Feedstock Base

The ownership pattern for the study area was described in three concentric circular areas centered on the FGE plant site. These three areas extend 12.5, 25.0, and 50.0 miles from Lincoln. Such divisions allow flexibility in assessing the magnitude of the residue base, given the uncertainties inherent in the economic modelling processes and subsequent results of such activities. The estimated CTL acreage present in each of the three areas is shown in Table 1-10. Two concerns should be noted in using these data. First, the CTL information was compiled by the state on or before 1977 from various sources; although such data do not become easily outdated (as it is essentially a biological measurement repeatable over time), the accuracy of the data is insufficient for detailed resource analysis. Secondly, the demarcated CTLs include areas already clearcut or in various stages of managed growth (e.g., commercial stand thinning, cull removal); such areas may not be available for residue harvest.

From Table 1-10, approximately 268,320 acres of CTL lands appear to be accessible to the potential FGE facility. If residue recovery is economically feasible out to 50-miles (from Lincoln), then the total acreage increases nearly four-fold to 1,051,680 acres. In order to estimate the annual range in residue production, a number of assumptions had to be made. These assumptions include:

- A conservative assumption (based largely on National Forest operations) that only 60 percent of the total CTL lands are suitable for timber harvest. The remaining acreage is presumably unsuitable for one or several of the following reasons: 1) they have been withdrawn from

TABLE 1-10.--COMMERCIAL TIMBERLAND OWNERSHIP PATTERNS AND ESTIMATED ACREAGES WITHIN SELECTED DISTANCES FROM LINCOLN, MONTANA

Ownership Category	Distance from Lincoln (Miles)		
	0.0 - 12.50	12.51 - 25.00	25.01 - 50.0
Montana State Forestry Lands[a]	800	0	16,480
Privately-Owned Timberlands[b]	14,720	36,960	239,840
U. S. Department of Agriculture			
Deer Lodge National Forest	0	0	213,120
Helena National Forest	114,560	51,840	89,760
Lewis and Clark National Forest	0	1,600	20,000
Lolo National Forest	0	6,560	127,520
U. S. Department of Interior			
Bureau of Indian Affairs (Flathead Reservation)	0	0	480
Bureau of Land Management	3,200	38,080	75,680
Bureau of Reclamation (Gibson Reservoir)	0	0	480
	Σ 133,280	Σ 135,040	Σ 783,360

Notes:

a) Does not include those lands managed for wildlife, park, and outdoor recreation purposes.

b) Includes lands owned/managed by U. S. Plywood, Burlington Northern, Montana Power, and non-industrial woodlots.

Source: BLM land ownership/CTL base map on file at MultiTech, Inc., Butte, Montana.

timber harvest by statute, administrative regulation, or by design in approved land use/resource management planning schemes; 2) they are no more than marginally suitable due to excessive development costs, low product values or resource protection constraints; or 3) they constitute a portion of the unregulated component (i.e., those CTLs not organized into timber production units managed under sustained yield principles.

- An average annual timber harvest rate of 1.05 percent of the total acreage (per cover type) over the duration of the FGE facility operations. This rate incorporates differences in present and potential future timber resource utilization strategies made by the various ownership categories. The previous results for the Anaconda FGE study (MultiTech, 1982) were used as guidance and are largely transferrable to the Lincoln area.
- A presumed species harvest distribution of 55, 40, and 05 percent respectively for those cover types dominated by lodgepole pine, Douglas fir, and "other" species. The presumed clearcut-to-partial cut ratios for these three categories are 75:25, 50:50, and 25:75, respectively. Again, the previous resource study was used for guidance as it appeared to be biologically transferrable (MultiTech, 1982).
- Only 65 percent of the total residues per acre will be harvested due to technical/economic constraints and allow for the maintenance of other resource values (e.g., to support soil recovery and maintain wildlife habitat, etc.).

The data from Table 1-10 and the above assumptions were used to calculate the average annual residue base potentially available to the FGE operations. It does not recognize the effects of competition from other industrial or residential sector users. The results shown in Table 1-11 indicate an annual residue production of 51,386 green tons (@ 55 percent by weight moisture content) within 25-miles of Lincoln. If the residues produced between 25 and 50 miles of Lincoln are economically accessible, than another 150,020 "green" tons of residues could be available to FGE production. In order to estimate the "worst-case" feedstock supply case, it was assumed that only 25 percent of those residues produced on private land will be available for FGE use, while 65 percent produced on federal and state lands will be available for FGE production. Such assumptions reduce the anticipated annual production figures to 29,442 tons within 25-miles radius of Lincoln; similarly, about 79,139 tons will be produced within 25 to 50 miles. These figures allow for residential use of the residues and recognize competition with other industrial users.

If the previously calculated value of 76 green lbs of residue feedstock per gallon of FGE produced is correct (MultiTech, 1982, p. 4-11), then annual FGE production could vary from 774,789 gallons to 2,082,605 gallons. Considering that the modelling results indicated a probable haul distance of 22.0 miles, it is recommended that the lower value above be used in calculating for engineering design and plant capacity.

TABLE 1-11.--SUMMARY OF ESTIMATED TOTAL AND AVERAGE ANNUAL RESIDUE PRODUCTION WITHIN THE LINCOLN STUDY AREA

Distance from Lincoln (Miles)		CTL Acreage per Cover Type[a]	Residue Production Per Cover Type (Tons $Acre^{-1}$)[b]	Potential Residue Production Per Cover Type (Tons)	Average Annual Production Per Cover Type (Tons)[c]
0-25	LPP:	88,546	40.7	3,603,822	34,056
	Df.	64,397	28.7	1,848,194	15,525
	0.	8,050	30.5	245,525	1,805
	Σ	160,993		Σ 5,697,541	Σ 51,386
25-50	LPP:	258,509	40.7	10,521,316	99,427
	Df.	188,006	28.7	5,395,772	45,325
	0.	23,501	30.5	716,780	5,268
	Σ	470,016		Σ 16,633,868	Σ 150,020

Notes:

a) Assumes harvest-by-cover-type ratio of 0.55 lodgepole pine (LPP); 0.40 Douglas fir (Df); 0.05 "other" species (0). Also presumes 60 percent availability of CT lands for actual harvest over the 25-years duration of FGE production.

b) Assumes down-dead biomass values (tons per acre) as follows: LPP, 18.4; Df 15.0; 0 15.9 (Brown and See, 1981, p. 6). Presumes green and standing-dead residue values (following timber harvest, in tons per acre) as follows: LPP, 44.2; Df 29.1; 0 31.0 tons per acre.* However, presume that of these totals only 65 percent of the residues are technically and economically feasible to harvest and transport, plus allow for the maintenance of other resource values.

c) Assumes that 1.05 percent of the total acreage (per cover type) is harvested per year, and the following clearcut: partial cut ratios occur per cover type: LPP 75:25; Df 50:50; 0 25:75. Partial cutting removes 60 percent of the total biomass present in the first cutting, and removes the remainder during the second cutting.

* (Benson and Schlieter, 1980, p. 3; Gage, 1978, p. 216.) These values sum respectively to LPP 62.6; Df 44.1; and 0 46.9 tons per acre.

1.3.2 Livingston Study Area

1.3.2.1 General Characteristics of the Forest/Residue Resource Base

Initially, it was decided that CTLs present within 50 miles of Livingston could be grouped into four forest cover types. The predominant species-associations and estimated (relative) proportions are as follows: 1) ponderosa pine/juniper "dry" sites, 0.10; 2) Douglas fir-lodgepole pine cool/dry sites, 0.70; 3) Englemann spruce-subalpine fir-lodgepole pine cool/moist sites, 0.15; and 4) "bottomland" plus "subalpine" sites (i.e., white bark and limber pines), 0.05. Furthermore, the species harvest distribution (on a species by acre basis) was assumed to be 48, 27, and 25 percent for Douglas fir, lodgepole pine and "other" species, respectively.

The above estimates utilized the literature cited in subsection 2.2.2.2, and the Resource Management Plan for the Billings Resource Area, (USDI, BLM, 1983; Climax Vegetation Map). Personal contacts included the following personnel from the Gallatin National Forest: Mr. Mike Shaw (October 28, 1982), Mr. Phil Cowan (February 25, 1983), Mr. Randy Gay (March 10, 1983), and Mr. Sam Gilbert (April 25, 1983).

Following from discussions with the above individuals, a representative stand of commercial timber was determined to have the characteristics given below:

- A multi-species (composite) average saw timber diameter at breast height (dbh) of 10 to 11 inches, with overall variations commonly in the 7 to 13-inch dbh range;

- Stems per acre of growing stock ranging from 250 to 350, with total trees per acre ranging from 150 to 650;
- Production of merchantable biomass varying from [illegible] to 25,000 board feet, but averaging closer to 10,000 bdft. For saw timber stands, the equivalent cubic feet volume averages 4,000 to 4,500, with an overall range of 1,400 to 7,000 cf acre^{-1}; and
- An average harvest volume defect (estimated error) of 10 percent.

In regard to commercial timber harvest practices, it was assumed that:

- At present, most of the logging done on CTL lands occurs on 25 to 35 percent slopes; however, as about 60 percent of the suitable CTLs occur on slopes of 40 or more percent, the average slope will increase (e.g., to 40 to 45 percent) over the FGE's operating lifetime.
- Ground skidding usually is done with medium-weight tracked or rubber-tired vehicles;
- Yarding distances commonly vary from 800 to 900 ft; and
- Forest-wide, multi-species scaling defects average from 5 to 7 percent.

Two additional assumptions were made on the basis of the above information on slope characteristics:

- At present, most timber harvest is done by hand-falling, although mechanical methods are used occasionally. On slopes greater than 40 percent, cable ground logging methods are practiced, which will become more prominent in the future; and
- Flat landings of about 75 x 150 feet are probably uncommon within the potential harvest area, so the chipping of residues will occur most likely at the FGE plant site.

Table 1-12 summarizes the representative number of pieces and equivalent biomass estimates by harvest component for mature stands of the various forest cover types present within the study area. The volume and piece estimates were derived in the same manner as done for the Lincoln site. The table indicates that an acre of representative CTL land contains about 5,351 cubic feet (cf) of harvestable biomass. Although this volume will result from close fiber utilization practices, two concerns must be recognized prior to harvesting it. Firstly, cost-effectiveness of residue gathering requires concurrent harvest along with the saw timber, poles, posts, etc. Secondly, a certain portion of the harvest residue must remain on-site so as to maintain/enhance other resource values such as soil or wildlife habitat.

Additional timber and residue haulage assumptions used in the harvest/transport cost estimations were as follows:

- The merchantable trunks are cut into 24-ft. sections, each having an average gross merchantable volume of 9.8 cf (Table 1-11);
- The usable residues range from seven to 32 ft. long, average 17.5 ft. (see Table 3 in Benson and Schlieter, 1980), and possess a gross volume of 5,351 cf per acre or an average per piece volume of 6.7 cf (Table 1-12);
- On-highway log trucks having a maximum capacity of 1040 cf and a load limit of 52,000 lbs is used to haul the timber/wood fiber; while
- Capacity is reduced to 30,000 lbs for pieces smaller than 10 cf due to "the difficulty of loading many small pieces on a truck" (Withycombe, 1980, p. A-6).

TABLE 1-12.--SUMMARY OF NUMBER OF PIECES AND EQUIVALENT BIOMASS ESTIMATES FEASIBLY HARVESTED PER ACRE FOR A MATURE, COMPOSITE, TIMBER STAND PRESENT WITHIN 50 MILES OF LIVINGSTON, MONTANA

Component		Number of Pieces	Equivalent Biomass (cf per acre)
Green Trees			
Merchantable Logs[a]		280	2,744
Cull[b]		28	274
Taps/Branches/Foliage[c]		280	1,820
Small Stems[d]		75	26
	Subtotal	663	4,864
Standing Dead[e]		65	312
Down Dead[f]		70	175
	Grand Total	798	5,351

Notes:

a) Assumes an average saw timber dbh of 10 inches, an average merchantable tree length of 24 ft., and an average total tree height of 32 ft; also assumes an average volume of 9.8 cf per merchantable section and about 16.3 cf for "full tree" volume.

b) Assumes harvest volume defect of 10 percent and a 9:1 ratio between mechantable pieces and cull pieces.

c) From note a), assume (16.3-9.8 =) 6.5 cf per top/branches/foliage unit.

d) Assumes average dbh and tip diameters of 2.5, 0.1 inches respectively and average (total) height of 10 ft; volume calculated using Smalian's Rule (Withycombe, 1980, Table 10), resulting in an average volume of 0.34 cf (including stem and foliage).

e) Extrapolated from Tables 3 and 4 in Benson and Schlieter, 1980. Assumes lengths ranging from 7 to 32 ft., dbh ≥ 2.5 inches and an average volume of 4.8 cf; this volume does not include crumbly rot.

f) Piece number extrapolated from Table 3 in Benson and Schlieter, 1980. Assumes lengths ≥ 7 ft. and an average volume of 2.5 cf.

In order to evaluate potential road quality between any given timber harvest area and the FGE facility site, the BLM ownership/CTL (base) map was inspected, along with the pertinent 250,000-scale AMS quandrangle sheet. From this inspection, the following road types and proportionate availability in the facility area were derived:

- Primary highways with excellent alignment and a slope range of ± 6 percent, present on 35% of the area;
- Double-lane secondary roads having a mixture of paved and graveled surfaces and a slope range of ± 8 percent, present on 30% of the area;
- Single-lane graveled roads with ditches, fair to poor alignment, and a slope range of ± 8 percent, present on 20% of the area; and
- Single-lane dirt roads without ditches, fair alignment, and a slope range of ± 8 percent, present on 15% of the area.

1.3.2.2 Determination of the Economically Feasible Residue Harvest and Transport Radius

The first approach towards estimating the economically feasible haul distance used the USDA Northern Rocky Mountain Zone average timber appraisal cost model, as adjusted for the assumed variability in harvest site conditions (USDA, National Forest Service, 1977). The results indicate a 1983 felling/limbing cost of $36.15 per thousand board feet (MBF), regardless of tree species harvested. Furthermore, the 1983 skidding cost was calculated to be $47.88 per MBF. The mechanics of these calculations are summarized in Table 1-13. As discussed previously, the costs of processing logging residues would be at least as expensive as those incurred for saw timber operations. The two cost estimates above probably represent the maximum likely costs for saw timber, and may be more applicable to logging residues. The USDA Zone

TABLE 1-13.--RATIONALE FOR APPRAISAL OF FELLING/LIMBING AND SKIDDING COSTS VIA USE OF THE USDA FOREST MANUAL (IN 1983 DOLLARS), FOR THE LIVINGSTON SITE AREA

FELLING/LIMBING COSTS[a]

Component	Percent Adjustment Factor
Average dbh = 10 inches	+ 28.0
Stem density = 373 acre^{-1}	- 2.0
Percent slope = 35-40	+ 5.0
Merchantable tree defect = 10%	- 8.0
TOTAL ADJUSTMENT	+ 23.0

Zone average (excluding rent, lease and depreciation) = \$24.25
Rent, lease and depreciation = \$6.32
Appraisal Cost Estimate: (\$24.25 x 1.230) + \$6.32 = \$36.15 MBF^{-1}

SKIDDING COSTS[b]

Component	Percent Adjustment Factor
Net volume acre^{-1} = 8922 MBF[c]	- 3.0
Average no. logs per gross MBF^{-1} = 27[d]	- 1.0
Skidding distance = 850 ft.	+ 3.3
Scaling defect = 6%	- 4.0
TOTAL ADJUSTMENT	- 4.7

Zone average (excluding rent, lease and depreciation) = \$42.71
Rent, lease and depreciation = \$7.18
Appraisal cost estimate: (\$42.71 x 0.953) + \$7.18 = \$47.88

Notes:

a) Taken from pp. 2422.41--2 and 2422.41--4 in Forest Manual, FSM 6/81 R-1 Supp 276.

b) Taken from pp. 2422.41--2 and 2422.41--6 in Forest Manual, FSM 6/81 R-1 Supp 276.

c) From Table 3-12, the total merchantable log volume plus standing dead volume equals 3056 cf; assume average ratio of 3.3 bd ft. per cf, thus equivalent to 10,085 MBF gross volume; the net volume is calculated using a harvest volume defect of 10 percent for merchantable logs and 25 percent for standing dead material.

d) Calculated by dividing gross MBF volume per acre by merchantable stems per acre, i.e., 10,085 ÷ 373 ≃ 27 stems per MBF.

average-derived appraisal costs (for saw timber and poles) tend to be greater than costs actually observed within the specific study area (MultiTech, 1982, p. 4-10). Data pertaining to cost estimations for loading/unloading and transportation of saw timber are given in Table 1-14; this information was combined with data from the previous table to estimate economically feasible haul distance. Table 1-15 shows in detail how an estimated one-way economic haul distance of 84.5 miles was derived.

The 84.5-mile estimate is highly optimistic, for the same reasons as discussed for Lincoln. In essence, the maximum likely haul distance for unchipped residues appears to be in the 40-to-50 mile range. The 84.5-mile estimate demonstrates that saw timber can be hauled economically approximately twice that distance, within the Livingston area.

The R. Withycombe (1980) cost appraisal model was used in the second approach for estimating the feasible haul distance. Information necessary for the use of this model is summarized in Table 1-16. The results, shown in Table 1-17, indicate saw timber and harvest residue can economically be hauled approximately 42.6 and 10.8 miles, respectively. These results assume break-even economics for both logger and plant operator (i.e., no profit-taking), and no external subsidizing of incurred costs. Finally, it should be recalled that the above haul distance estimates assume tractor skidding methods of fiber yarding. Dr. Withycombe concluded that "the very high cost of cable yarding at average piece sizes of less than 15 or 20 cubic feet (0.4 or 0.6 m^3) precludes cable yarding as a reasonable alternative" (1980, p. A-6). Logging operations using the cable yarding method will become more common as time progresses. Table 1-18 presents the rationale for concluding that cable

TABLE 1-14.--RATIONALE FOR APPRAISING TIMBER LOADING AND HAULAGE COSTS VIA USE OF THE USDA *FOREST MANUAL* APPROACH

Component	Value Utilized
Gross volume (green tons)[a]	21.5
Loading Time (minutes)[b]	70
Road Quality--see discussion in text	
Averaged Speed (mph)[c]	11.7
Transport Costs	
Fixed daily costs[d]	$ 70.49
Labor per day[e]	$208.23
Unloading time (minutes)[f]	54

Notes:

a) Presumably the maximum volume capable of being hauled, given the small lengths and volume-per-piece characteristics of the materials, (see p. 3-7).

b) Extrapolated from Table 2, p. 2422.41--21 in the USDA *Forest Manual* (1977); the weighted value derived from this table was multiplied by 1.5 to adjust for added difficulty in loading these materials.

c) Extrapolated from Table 3, p. 2422.41-23 in the USDA *Forest Manual* (1977); the weighted average mph was calculated as follows: (15.87 x 0.35) + (10.43 x 0.30) + 8.62 x 0.20) + (8.68 x 0.15) ≃ 11.7 mph.

d) Calculated from p.2422.41--18 in the USDA *Forest Manual* (1977) = $17,271 ÷ 245 = $70.49 per operating day.

e) Calculated from p. 2422.41--18 in the USDA *Forest Manual* (1977), but using a 10-hour work day = $249.87 x 10/12 = $208.23 day^{-1}.

f) Author's observations/impressions gained while serving as an employee for the Flathead National Forest Service, summers of 1971-1976.

TABLE 1-15.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAUL DISTANCE, USING THE USDA FOREST MANUAL MODEL (IN 1983 DOLLARS)

CRITICAL ASSUMPTION: The FGE facility must be able to pay up to \$43.60 green ton^{-1}, thus remaining competitive with the anticipated pulpwood/fiber product markets (and possibly with the house log market--see Keegan, 1982).

APPROACH:

1. Assume in-plant chipping and associated handling costs of \$3.82 green top^{-1} (see Table 4-9 in MultiTech, 1982; adjusted to 1983 dollars via use of a 9 percent inflation of the original 1981 value).

2. Ceiling price per load: 21.5 green tons load^{-1} x \$43.60 green ton^{-1} = \$937.40 load^{-1}.

3. Conversion of MBF to green tons: \$84.03 MBF^{-1} x 1 MBF/1000 BF x (10 lbs/BF)$^{-1}$ x 2000 lbs. ton^{-1}, equivalent to \$16.81 green ton^{-1}. The lbs. per bd. ft. conversion was taken from Table II in Withycombe, 1980.

4. Expression for calculating the economically feasible haulage radius:

   a) $\$937.40 = \$361.42 + (2.067 \text{ hrs.} \times \$20.82 \text{ hr.}^{-1}) + \dfrac{\text{distance (in miles)}}{11.7 \text{ mph}} \times \$20.82 \text{ hr.}^{-1} + \text{distance (miles)} \times \$0.888 \text{ mile}^{-1}] + \$82.13$ (for chipping, load^{-1});

      The weighted cost mile^{-1} factor, contained within the brackets, utilized the Forest Manual's cost mile^{-1} values of 0.5224 and 1.5674 for paved and unpaved roads, respectively (Forest Manual, 1977, p. 2422.41--18). The mechanics of calculating the above factor are as follows:

      [highway driving proportion, 0.35 + double-lane driving proportion, 0.30] x \$0.5224 mile^{-1} + [single-lane gravel road driving proportion, 0.20 + single-lane dirt road driving proportion, 0.15] x \$1.5674 mile^{-1} = \$0.8881 mile^{-1} = \$0.888 mile^{-1}.

   b) \$937.40 - \$361.42 - \$43.03 - \$82.13 = (\$1.780 mile^{-1} + \$0.888 mile^{-1}) = \$2.668 mile^{-1} traveled.

   c) Thus, by dividing the residual price per load by the travel cost per mile, the total miles allowed for travel (and still break even on costs) can be calculated. The results of this calculation are shown below.

      "Haulage allowance" (in miles) = $\dfrac{\$450.82}{\$2.668 \text{ mile}^{-1}}$ = 169.0 miles round trip.

TABLE 1-16.--SUMMARY OF DATA NEEDS FOR INPUT INTO THE R. WITHYCOMBE COST ESTIMATE MODEL (EXPRESSED AS 1983 DOLLARS PER GREEN TON).

	Fiber Type	
Component	Saw Timber[a]	Logging Residues[b]
Hand felling and limbing costs	4.73	49.18
Grapple skidding costs[c]	4.21 to 6.18[d]	4.21 to 19.79[e]
Loading/hauling costs[f]	6.74	11.48
Unloading Costs[g]	3.46	6.84
$\sum$	\$19.14 to \$21.11	\$71.71 to \$87.29

Notes:

a) Assumes an average saw timber dbh of 11.5 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

b) Assumes an average dbh of 4.5 inches. Cost estimates are extrapolated from Table 1 in R. Withycombe, 1980.

c) Assumes an average grapple skidding distance of 850 ft., average saw timber volume of 9.8 cf per 24 foot section, and an average residue volume of 1.5 cf per 18 foot section. Cost estimates are extrapolated from Table 3 in R. Withycombe, 1980.

d) The lower cost follows from the optimistic assumption that each load will have a volume of 150 cf; the higher cost follows from the more conservative assumption that only 10 stems can be carried per load, totalling 98 cf volume.

e) The lower cost follows from an optimistic assumption that each load will have a volume of 150 cf; the higher cost follows from the more conservative assumption that only 20 stems can be carried per load, totalling 30 cf volume.

f) Assumes an average (one-way) haul distance of 25 miles and road conditions similar to those utilized in the Forest Manual cost appraisals. Cost estimates are extrapolated from Table 5 in R. Withycombe, 1980, using the average volume per piece estimates contained in Note c, above.

g) Assumes same saw timber and residue dbh averages as given in Note c, above. Cost estimates extrapolated from Table 8 in R. Withycombe, 1980.

TABLE 1-17.--SUMMARY CALCULATIONS FOR ESTIMATING THE ECONOMICALLY FEASIBLE HAUL DISTANCE USING THE WITHYCOMBE MODEL (IN 1983 DOLLARS).

CRITICAL ASSUMPTION: The same as given in Table 1-15 (i.e., a \$43.60 green ton^{-1} ceiling on as-received residue feedstock).[a]

APPROACH:

1. Assume in-plant chipping and handling costs of \$3.82 per green ton (see Table 1-13).
2. Assume ceiling price per 21.5 ton shipment of \$937.40 (see Table 1-15).
3. Assumed resource costs per green ton: a) an average saw timber cost of \$20.12, and b) an average residue cost of \$79.50 (taken from Table 1-14).
4. Input pertinent values into the same equation form as presented in Table 1-15. The estimate for total haulage distances judged to be economically feasible are as follows: a) for saw timber, 85.2 miles (i.e.,~ 42.6 miles radius) and b) for residues, 21.6 miles (i.e.,~ 10.8 miles radius).

Note:

a) The following additional assumptions were utilized in the calculations:

1) an average speed of 11.7 mph and a tractor/trailer operating cost of \$0.888 mile^{-1};

2) loading/unloading times totaled to 2.067 hours; and

3) a \$37.12 hour^{-1} cost for the log truck and driver (extrapolated from p. A-7 in Withycombe, 1980 and adjusted to 1983 dollars).

TABLE 1-18.--SUMMARY CALCULATIONS FOR ESTIMATING ECONOMICALLY FEASIBLE HAULAGE DISTANCES, PRESUMING A CABLE-YARDING SYSTEM (IN 1983 DOLLARS)

CRITICAL ASSUMPTION: The same as given in Table 1-13 (i.e., \$43.60 green ton^{-1} ceiling on as-received residue feedstock).

APPROACH:

1. Assume in-plant chipping and handling costs of \$3.82 per green ton (see Table 1-15).

2. Assume ceiling price per 21.5 ton shipment of \$937.40 (see Table 1-15).

3. Assume an average cable yarding distance of 1000 ft., average saw timber volume of 9.8 cf per 24 ft. section, and an average residue volume of 1.5 cf per 18 ft. section. Cost estimates are extrapolated from Table 4 in R. Withycombe, 1980. The respective values used are \$27.34 green ton^{-1} and \$159.43 green ton^{-1}.

4. Assumes hand felling-limbing, loading-hauling, and unloading costs per fiber type are the same as given in Table 1-16. Thus, total cost estimates per fiber type are \$42.27 green ton^{-1} saw timber and \$226.93 green ton^{-1} for residues.

5. As all the other parameters are held constant, the respective radii are calculated as follows:

   a) for saw timber, $(20.12/42.27)(42.6) \approx 20.3$ miles, and
   b) for residues, $(79.50/226.93)(10.8) \approx 3.8$ miles.

yarding could shrink the feasible saw timber haul distance to 20.3 miles (holding all other factors the same as in Tables 1-16 and 1-17). Furthermore, the feasible haul distance for residues could decrease to about 3.8 miles. Although there is a trend towards developing small cable yarding systems, "the cost reductions are unlikely to be enough to make cable yarding of small residues economically feasible," (Withycombe, 1980, p. A-6).

Overall, the economically feasible haul distance estimate is very sensitive to assumptions made pertaining to timber and wood fiber harvesting, transport, and in-plant processing costs. Credible estimates of the economically feasible haul distance for wood residues ranges from under 4 miles to over 40 miles. As the Withycombe model is better designed to evaluate wood residue harvesting costs (than is the Forest Manual), the arithmetic average of these estimated economic haul distance represents a moderate figure of approximately 22 miles. This is not to say that the use of the Forest Manual approach was an academic exercise; the harvest of commercial saw timber within 80 or so miles from Livingston appears to be economically feasible. However, given the magnitude of economic investment (risk) involved in constructing and operating a large ($\geq$ 0.67 million gallon per year) FGE facility, and given the degree of accuracy in the model's parameters, a residue haul distance approaching 40 miles cannot be recommended at this time.

The major topographic and cultural features present within 15 miles of the plant site are shown in Figure 1-4.

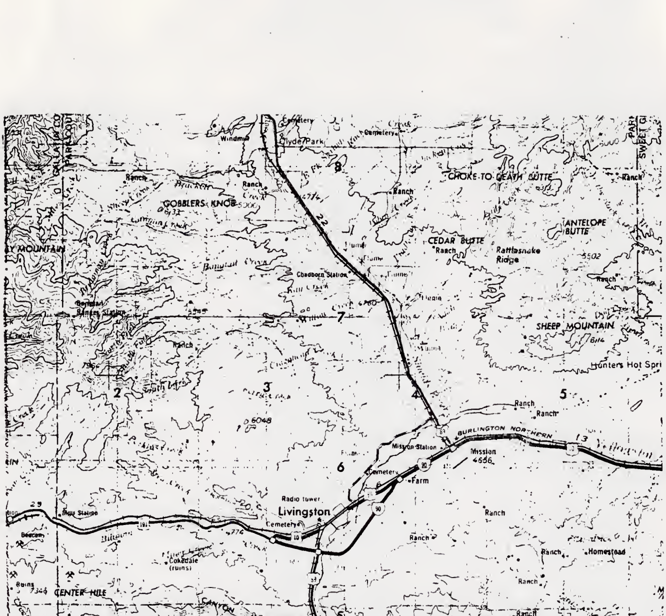

FIGURE 1-4.--RESOURCE STUDY AREA MAP FOR THE LIVINGSTON FGE SITE

1.3.2.3 Estimation of Magnitude of the Residue Feedstock Base

The ownership pattern for the study area was described by three concentric circular areas extending 12.5, 25.0, and 50.0 miles from the Livingston townsite. Such divisions allow flexibility in assessing the magnitude of the residue base, given the uncertainties inherent in the economic modelling processes, (and subsequent results of such activities). The estimated CTL acreage present within each of the three areas is shown in Table 1-19. Two concerns should be noted in using these data. First, the CTL information was compiled by the state on or before 1977 from various sources; although such data do not become easily outdated (as it is essentially a biological measurement repeatable over time), the accuracy of the data is insufficient for detailed resource analysis. Second, the CTLs include areas already clearcut or in various stages of managed growth (e.g., commercial stand thinning, cull removal); such areas may not be available for residue harvest.

From Table 1-19, about 84,960 acres of CTL lands appear to be accessible to the (potential) FGE facility. If residue recovery is economically feasible out to 50 miles from Livingston, then the total acreage increases nearly 3.5-fold to 293,280 acres. In order to estimate the annual range in residue production, a number of assumptions had to be made:

- Only 60 percent of the total CTL lands are suitable for timber harvest. The remaining acreage is presumably unsuitable for one or several of the following reasons: 1) they have been withdrawn from timber use by statute, administrative regulation, or by design in approved land use/resource management planning schemes; 2) they are no more than

TABLE 1-19--COMMERCIAL TIMBERLAND OWNERSHIP PATTERNS AND ESTIMATED ACREAGES WITHIN SELECTED DISTANCES FROM LIVINGSTON, MONTANA

	Distance from Livingston (Miles)		
Ownership Category	0.0 - 12.50	12.51 - 25.00	25.01 - 50.0
Privately-Owned Timberlands[a]	2,880	12,000	35,680
U. S. Department of Agriculture			
Beaverhead National Forest	0	0	5,280
Custer National Forest	0	0	5,120
Gallatin National Forest	5,600	61,600	133,920
Helena National Forest	0	0	2,560
Lewis and Clark National Forest	0	0	24,960
U. S. Department of Interior			
Bureau of Land Management	2,880	0	800
	Σ 11,360	Σ 73,600	Σ 208,320

Note:

a) Includes industrial timberlands owned by Burlington Northern and non-industrial woodlots.

Source: BLM land ownership/CTL base map on file at MultiTech, Inc., Butte, Montana.

marginally suitable due to excessive development costs, low product values or resource protection constraints; or 3) they constitute a portion of the CTLs not organized into timber production units managed under sustained yield principles.

- An average annual timber harvest rate of 1.05 percent of the total acreage (per cover type) over the duration of the FGE facility operations. This rate probably incorporates differences in present and future timber resource use strategies made by the various ownership categories. The previous results for the Anaconda FGE study (Multi-Tech, 1982) were used as guidance and are largely transferrable to the Livingston area.
- A species harvest ratio of 0.27:0.48: 0.25 respectively for those cover types dominated by lodgepole pine, Douglas fir, and "other" species. The presumed clearcut-to-partial cut ratios for these three categories are 50:50, 75:25, and 25:75, respectively. Again, the previous resource study was used for guidance, as it appeared to be biologically transferrable (MultiTech, 1982).
- Only 65 percent of the total residues per acre will be harvested due to technical/economic constraints, and allow for the maintenance of other resource values such as vegetation recovery and wildlife habitat.

The data from Table 1-19 and the above assumptions were used to calculate the average annual residue base potentially available to the FGE operations. It does not recognize the affects of competition from other industrial or residential users. The results, shown in Table 1-20, indicate an annual residue production of 12,413 green tons (@ 55 percent by weight moisture content) within 25-miles of Livingston. If the residues produced between 25 and 50

TABLE 1-20.--SUMMARY OF ESTIMATED TOTAL AND AVERAGE ANNUAL RESIDUE PRODUCTION IN THE LIVINGSTON STUDY AREA

Distance from Livingston (Miles)	CTL Acreage per Cover Type[a]		Residue Production Per Cover Type (Tons Acre^{-1})[b]	Potential Residue Production Per Cover Type (Tons)	Average Annual Production Per Cover Type (Tons)[c]
0-25	LPP:	13,764	39.4	542,302	5,124
	Df.	24,468	24.4	597,019	5,014
	O.	12,744	21.4	272,722	2,005
	Σ	50,976		Σ 1,412,043	Σ 12,413
25-50	LPP:	33,748	39.4	1,329,671	12,566
	Df.	59,996	24.4	1,463,902	12,298
	O.	31,248	21.4	668,707	4,914
	Σ	124,992		Σ 3,462,280	Σ 29,778

Notes:

a) Assumes that 60 percent availability of CT lands for actual harvest over the 25 year duration of FGE production; also presumes harvest-by-cover type ratios of 0.27 lodgepole pine (LPP); 0.48 Douglas fir (Df); and 0.25 "other" species (O).

b) Assumes down-dead biomass values (in tons acre^{-1}) as follows: LPP 17.8; Df 12.8; O 16.3 (Brown and See, 1981, p. 6). Presumes green and standing-dead residue values (following timber harvest, in tons acre^{-1}) as follows: LPP 42.8; Df 24.8; O 16.7 (using data from Table 3-9 and Benson and Schlieter, 1980, p. 3, as adjusted for forests on east side of the continental divide). These values sum respectively to: LPP 60.6; Df 37.6; O 33.0 tons per acre. However, it is presumed that of these totals only 65 percent of the residues are technically and economically harvestable and transportable, plus allow for maintenance of other resource values.

c) Assumes that 1.05 percent of the total acreage (per cover type) is harvested per year, and the following clearcut:partial cut ratios per cover type: LPP 75:25; Df 50:50; O 25:75. Partial cutting removes 60 percent of the total biomass present in the first cutting, and removes the remainder during the second cutting.

miles of town are economically accessible, then another 29,778 tons of residues could be available for FGE production. In order to estimate the "worst-case" feedstock supply case, it was assumed that only 25 percent of the residues produced on private land will be available for FGE use, while 65 percent produced on federal lands will be available. Such assumptions reduce the anticipated annual production figures to 7,199 tons within 25 miles of Livingston, and 24,514 total tons within 50 miles.

If the calculated value of 76 green pounds of residue feedstock per gallon FGE produced is correct (MultiTech, 1982, p. 4-11), then annual FGE production will vary from approximately 189,447 gallons to about 645,105 gallons. Given the uncertainties inherent in the resource and economic analyses, it is recommended that the lower value (above) be used in determining the optimum plant capacity.

2.0 MILL WASTE AND OTHER FIBER RESOURCE INVENTORY STUDY

2.1 INTRODUCTION AND DEFINITIONS

The Milestone 2 Report was prepared with two major objectives in mind. The first of these was the estimation of economically available quantities of mill residues present within a prescribed distance from the potential FGE sites at Lincoln and Livingston. The second objective was the estimation of secondary sources of combustible fiber wastes economically available for each FGE facility. In response to these objectives, the Milestone 2 Report described the locations and physical characteristics, and assessed the respective economic viabilities of using the wastes of the type defined in FGE production operations.

The residues generated by the primary forest industry are of two general types: 1) those resulting from "in-woods" timber management/harvest activities; and 2) those resulting from forest-products primary and secondary manufacturing processes. The former category was addressed in the Milestone 1 Report (MultiTech, 1983), and will not be discussed further in the present report. The latter category arises from the manufacturing of such products as dimension lumber, plywood, and wood pulp. The various mill residues produced by such manufacturing activities include:

- Coarse, chippable residues such as wood slabs, edges, and trimmings;
- Cores from plywood manufacture, which in Montana are usually cut into lumber (Keegan and White, 1979);
- Fine residues composed of sawmill planer shavings and sawdust, sawdust from veneer mills, and panel trimmings from the layup mill;

- Bark from lumber and plywood manufacturing;
- Bark from pulp and paper mills that debark green pulping stock; and
- Fine residues generated by cabinet-making and other mill work.

The "secondary" fiber resources present at municipal dump/landfill sites and at community recycling centers may provide additional feedstock for FGE production (Cheremisinoff et al., 1976). These potential resources are defined in the following paragraph.

Considerable amounts of wood and wood fiber products are discarded daily as municipal solid waste. Paper is a major component of this refuse and possesses a great salvage potential. At present, newsprint is selectively collected, graded, and baled at the various recycling centers located throughout the two study regions. Once de-inked via mechanical and/or chemical treatment(s), the processed paper fiber can serve as a supplemental feedstock for ethanol production. If economical, the feedstock may also include a mixture of old fiber containers and non-waxed boxboard, old wrapping paper, paper bags, discarded books and magazines. Convenient sources for such wastes include office buildings, large retail outlets, warehouses, and transportation terminals. Wood waste produced by local construction and demolition/salvage activities is an additional potential source of wood fiber. Cooperation and coordination of groups generating such wastes could result in a relatively homogeneous, minimally contaminated (e.g., by waxes, dyes, metal) source of secondary fiber. Properly managed, the relatively low flow rate of such materials may provide a reliable supplement to the wood-waste acquired from forest and mill activities.

2.2 METHODOLOGIES UTILIZED

2.2.1 Mill Residue Inventory

The site-specific inventories were performed with two objectives in mind. The first was the estimation of the amount of coarse and fine mill residues produced annually by sawmill, post and pole, and secondary manufacturing operations within 50 miles of each potential FGE site. The second objective was to develop an estimate of how much residue would be available over the long-term for FGE production.

The rationale for designating a 50-mile haul distance is two-fold. First, it did not exclude any major source of residues previously uncommitted (over the long-term) to another industrial use(s), particularly those associated with the Champion International operations in the Missoula area. Therefore, all commercially attractive sources are included. The FGE feasibility study performed for the Anaconda area indicated that Champion International and Louisiana Pacific probably use at least 90 percent of all such residues produced within 200 miles of Missoula (MultiTech, 1982, pp. 4-30, 4-31). Although hogfuel may be in surplus until approximately 1985, the above "consumption radius" estimate still appears to be reasonable (Mr. Jack Fisher, Manager of Champion International's Frenchtown operations, personal communication). It is suggested that residue quantities too small to be economically collected and transported to Missoula would serve as the chief sources of mill waste feedstock for either FGE facility.

Secondly, the relatively small and diffuse quantities of uncommitted residues will be transported to the FGE sites by truck. D. A. Tillman (1978, p. 94) presents guidelines of maximum cost-effective transportation radii (by truck) that vary from 40-miles for unprocessed softwood (@~ 45 percent-by-weight moisture) to 90-miles for softwood pellets (@~ 15 percent-by-weight moisture). Based upon the above phone conversation with Mr. Fisher and economic data on softwood pelletizing costs from O'Grady et al. (1980), it appears that chips can be hauled at approximately half the cost (per ton-mile) as can pellets. In fact, chips can be hauled up to 200-miles at a cost less than haulage of pellets over one-way distances of 50-miles. Therefore, the designated 50-mile radius set for the present study is probably optimistic, given the presumed competition and economic constraints of up-grading the residues prior to transport to the particular FGE facility.

A state-wide directory of forest product industries served as the primary source of information on contacting operators within both study areas, (Montana Department of State Lands, 1983). The operators were interviewed by phone, thus acquiring data satisfying the above objectives. This information was supplemented with a literature review and data gleaned from previous contacts with federal and Montana State forestry personnel.

Site-specific methodologies are presented in the following subsections. The mill residue inventory results are presented in subsection 2.3.1.1 for the Lincoln site and in subsection 2.3.2.1 for the Livingston site.

2.2.1.1 Lincoln Study Area

Sawmills, post and pole mills, and secondary manufacturing operations within 50 miles of Lincoln were determined in the state-wide directory. Local telephone directories and operator assistance were used occasionally to supplement the state directory's information. The sawmill and post and pole operators contacted are presented in Table 2-1, while the secondary manufacturers contacted are shown in Table 2-2. The state wood products directory listed a number of firms in the study area that could not be reached by phone despite repeated attempts over a number of weeks. Given the recent publication date (1983) of the directory, the unaccessible firms probably are still in business, but on an intermittent basis.

2.2.1.2 Livingston Study Area

The sawmill and post and pole operators contacted are presented in Table 2-3; the secondary manufacturers contacted are shown in Table 2-4. As was the case for Lincoln, a number of the operations listed in the state directory could not be contacted by phone. Many of these unaccessible listings probably are intermittent operations. However, at least one of the sawmills, Burkland Studs, Inc., has gone out-of-business since publication of the directory.

TABLE 2-1.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a]

A. SAWMILLS

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Granite	Granite Timber Treating Porter's Corner Philipsburg, MT 59858	A	Mr. Mark Metesh 859-3391
	Hall/Alt Lumber Company Box 38 Hall, MT 59837	B	Mr. Jay Krieg 288-3289
Lewis and Clark	Bouma Post Yard Box 108 Lincoln, MT 59639	N/A (~ 350,000 pieces year^{-1})	Mr. Louie Bouma 362-4222 (Lincoln) Mr. Harry Bouma 466-2140 (Choteau)
	Champion Building Products Box 854 Helena, MT 59601	E	Mr. Oscar Olson 442-8636
	Gean Debree Birdseye Road Helena, MT 59601	A	Mr. Gean Debree 442-8879

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

TABLE 2-1.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a] (Continued)

A. SAWMILLS (Contd)

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Lewis and Clark (Contd)	Martin R. Drivdahl 5547 Birdseye Road Helena, MT 59601	A	Mr. Martin Drivdahl 442-2783
	Morris Lumber Co. 4540 Birdseye Road Helena, MT 59601	A	Mr. Bud Morris 443-3300
	R and R Lumber Lincoln, MT 59648	A	Mr. Allen Routzhan 362-4270
	Warren Wood Sawmill Box A East Helena, MT 59635	A	Mr. Warren Wood 227-6785
	Woodhurst Lumber General Delivery Lincoln, MT 59639	A	Mr. Jim Ray 362-4654

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

TABLE 2-1.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a] (Continued)

A. SAWMILLS (Contd)

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Missoula	Jerry Montelius P.O. Box 11 Clinton, MT 59825	A	Mr. Jerry Montelius 825-6701
	Pyramid Mountain Lumber Co. Box 20 Seeley Lake, MT 59836	D	Mr. Doug Mode 677-2201
	Dave Sheets P.O. Box 119 Clinton, MT 59825	A	Mr. Dave Sheets 825-6811 Mr. John Sheets 825-4163
Powell	Joe Applegate 100 Boulder Road Deer Lodge, MT 59772	A	Mr. Joe Applegate 846-2560
	Laurence Beck North of Deer Lodge Deer Lodge, MT 59713	A	Mr. Laurence Beck 846-2402

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).
b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

TABLE 2-1.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a] (Continued)

A. SAWMILLS (Contd)

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Powell (Contd)	Soren Beck Avon, MT 59713	A	Mr. Soren Beck 492-8195
	Louisiana-Pacific Corp. Kentucky Avenue Deer Lodge, MT 59722	E	Mr. Dick Rydeen 846-1600

B. POST AND POLE PROCESSORS

County	Firm	Process Type[c]	Personal Contact/ Phone Number
Granite	Granite Timber Treating Porter's Corner Philipsburg, MT 59858	CS-NP; P-O	Mr. Mark Metesh 859-3633

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

c) Two sets of codes are given: the first relates to treatment plant type, while the second relates to the type of preservative used. The former codes include CS = cold soak, NP = non-pressure, and T = thermal. The latter codes include P = Penta, and O = oil-borne.

TABLE 2-1.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a] (Continued)

A. POST AND POLE PROCESSORS (Contd)

County	Firm	Process Type[c]	Personal Contact/ Phone Number
Lewis and Clark	Blackfoot Treating Plant Box 304 Lincoln, MT 59639	T-NP; P	Mr. Gerald Baresch 362-4250
	Bouma Post Yard Box 108 Lincoln, MT 59639	CS-NP; P-O	Mr. Louie Bouma 362-4222

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

c) Two sets of codes are given: the first relates to treatment plant type, while the second relates to the type of preservative used. The former codes include CS = cold soak, NP = non-pressure, and T = thermal. The latter codes include P = Penta, and O = oil-borne.

TABLE 2-2.--SUMMARY OF SECONDARY MANUFACTURING OPERATIONS CONTACTED WITHIN 50 MILES OF LINCOLN, MONTANA[a]

County	Firm	Products	Personal Contact/ Phone Number
Lewis and Clark	Foley's Cabinet and Fixture 3205 2nd Avenue Box 4075 Helena, MT 59601	Cabinets and Millwork	Mr. Pat Foley 442-3431
	Lincoln Log Cabins Box 48 Lincoln, MT 59639	Log Homes about (50 per year)	Mr. Gerald Baresh 362-4259
	Yuhas Millwork 2201 Hauser Box 952 Helena, MT 59601	Architectural Millwork, Cabinets and Panelling	Mr. Quinton Yuhas 442-4707

Note:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

TABLE 2-3.--SUMMARY OF SAWMILL AMD POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LIVINGSTON, MONTANA[a]

A. SAWMILLS

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Gallatin	Lumber Enterprises Canyon Route Gallatin Gateway, MT 59730	A	Mr. Doug Flament 763-4411 Mr. Dave Hargrove 763-4416
	Plum Creek Box 325 Belgrade, MT 59714	D	Mr. Bill Purcell 388-4221
Park	Brand S. Lumber Company Box 1033 Livingston, MT 59047	C	Mr. Dick Webb 222-3360
	Dave Menuey East of Cooke City Cooke City, MT 59020	A	Mr. Dave Menuey 838-2392
	Sarrazin Lumber Company Box 122 Clyde Park, Mt 59018	A	Mr. Bob Sarrazin 686-4447
	Willow Creek Lumber Co. Box 1297 Livingston, MT 59047	B	Mr. Bob Hansen 222-6240

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

TABLE 2-3.--SUMMARY OF SAWMILL AND POST AND POLE OPERATORS CONTACTED WITHIN 50 MILES OF LIVINGSTON, MONTANA[a] (Continued)

A. SAWMILLS (Contd)

County	Firm	Size Class[b]	Personal Contact/ Phone Number
Sweet Grass	Ralph Cosgriff Big Timber, MT 59011	A	Mr. Ralph Cosgriff 932-2483
	Timberline Sawmill Box 1073 Big Timber, MT 59011	A	Mr. Bruce Ricker 932-3653
	Morris Tronrud, Jr. Melville, MT 59055	A	Mr. Morris Tronrud, Jr. 537-4475

B. POST AND POLE PROCESSORS

County	Firm	Process Type[c]	Personal Contact/ Phone Number
Gallatin	Belgrade Post Yard Route #1 Box 196 Belgrade, MT 59714	CS-NP; P-O	Mr. Jerry Beagley 388-6760
	Idaho Pole Company Box 1129 Bozeman, MT 59715	P,T-NP; P-O	Mr. Todd Brown 587-5181

Notes:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

b) The following size class codes are pertinent to the above mills: A = less than 3,000 MBF (thousand board feet) per year; B = 3,000 to 5,000 MBF yr^{-1}; C = 5,000 to 10,000 MBF yr^{-1}; and D = 10,000 to 25,000 MBF yr^{-1}.

c) Two sets of codes are given: the first relates to treatment plant type, while the second relates to the type of preservative used. The former codes include CS = cold soak, NP = non-pressure, and T = thermal. The latter codes include P = Penta, and O = oil-borne.

TABLE 2-4.--SUMMARY OF SECONDARY MANUFACTURING OPERATIONS CONTACTED WITHIN 50 MILES OF LIVINGSTON, MONTANA[a]

County	Firm	Products	Personal Contact/ Phone Number
Gallatin	Hoeger Wood Products Box 272 Gallatin Gateway, MT 59720	Survey Stakes	Mrs. Virginia Hoeger 763-4442
	Lumber Enterprises, Inc. 7577 Gallatin Road Bozeman, MT 59715	Log Homes (about 240 per year)	Mr. Dave Hargrove 763-4411

Note:

a) Information taken from the 1983 Directory of Montana's Forest Products Industry. (Montana Department of State Lands, Foresty Division, Missoula, 1983).

2.2.2 Municipal Wood Fiber Recovery and Waste Paper Recycling Contributions

2.2.2.1 Municipal Wood Fiber Recovery

The major objective of this inventory was the estimation of annual processable waste production within and adjacent to particular municipalities within 50 miles of each potential FGE site. Lesser objectives included the following: 1) an estimation of economic availability of such materials, given the calculated costs of collection, transport, handling, etc; and 2) an evaluation of the effects of competition among the various potential consumers of the municipal wood fiber.

The Executive Summary and Region IV Final Report for the Montana State Solid Waste Management Strategy document were used to satisfy the above objectives (Henningson *et al.*, 1976a, b). The processable waste figures listed in these reports do not include earth and fill material, "bulky materials," or debris from construction or demolition projects. Henningson *et al.* observed that 77 percent by weight of the processable wastes are combustible (Executive Summary, p. 3). The present study assumes that this weight percent is also fermentable, i.e., being suitable for use as FGE feedstock.

The municipal wood fiber inventory results are presented in subsection 2.3.1.2 for the Lincoln site and in subsection 2.3.2.2 for the Livingston site.

2.2.2.2 Waste Paper Recycling Contributions

The major objective of this inventory was the estimation of the quantities of newsprint, cardboard, and other paper waste processed by the particular recycling centers operating within reasonable distances of the respective FGE sites. A lesser objective was the evaluation of competition effects (i.e., resource availability), given the knowledge that much of the wastes produced at present are used in producing pulp and insulation.

The data for recycled paper products were acquired via phone interviews of the managers of those centers pertinent to this study. Key information for each center operating within the Lincoln study area is shown in Table 2-5, Part A; the equivalent information for the Livingston study area is shown in Table 2-5, Part B.

The recycled paper inventory results are presented in subsection 2.3.1.3 for the Lincoln site and in subsection 2.3.2.3 for the Livingston site.

2.3 STUDY RESULTS

2.3.1 Lincoln Study Area

The methodologies discussed in Section 2.2 were applied to inventorying the defined waste fiber categories within approximately 50 miles of Lincoln. The estimated annual production of coarse and fine residues arising from sawmill and secondary manufacturing processes is presented in subsection 2.3.1.1. The potential recovery of processable wood fiber from municipal solid waste

TABLE 2-5.--WASTE PAPER RECYCLING CENTERS PRESENT WITHIN THE VICINITIES OF THE LINCOLN AND LIVINGSTON, MONTANA FGE STUDY SITES[a]

PART A. LINCOLN FGE SITE AREA

County	Firm	Fiber Materials Recycled	Personal Contact/Phone Number
Cascade	Great Falls Recycling Center 700 2nd Street Great Falls, MT 59405	Newspaper, cardboard, white newsprint, computer printouts	Mr. Ray Quigley 452-4192
Lewis and Clark	Montana Recycling Center 933 Getchell Helena, MT 59601	Newspaper, computer printouts, cardboard	Mr. Frank Bushilla 443-7587
Missoula	Five Valley Recycling 3010 Reserve Missoula, MT 59801	Newspaper, computer printouts, ledger paper, cardboard	Mr. Dale Traver 549-2267
	Missoula Recycling Center 806 West Spruce Street Missoula, MT 59801	Newspaper, ledger paper, computer printouts and cards, old corrugated containers	Mr. Doug Stewart 721-1120

Note:

a) The respective address and phone number per contact were acquired from phone directories. Names of persons were obtained during the specific interview.

TABLE 2-5.--WASTE PAPER RECYCLING CENTERS PRESENT WITHIN THE VICINITIES OF THE LINCOLN AND LIVINGSTON, MONTANA FGE STUDY SITES[a] (Continued)

PART B. LIVINGSTON FGE SITE AREA

County	Firm	Fiber Materials Recycled	Personal Contact/Phone Number
Butte-Silver Bow	Butte Recycling Center 616 East Front Street Butte, MT 59701	Newspaper only	Mr. Don Hilmo 723-6440
Gallatin	Bozeman Recycling Center 725 East Cottonwood Bozeman, MT 59715	Newspaper and computer printouts	Mr. Lee Bakke 587-4853
Yellowstone	Billings Recycling Center 458 Charles Billings, MT 59101	Newspaper and corrugated boxes	Mr. Mark Richlen 252-5721

Note:

a) The respective address and phone number per contact were acquired from phone directories. Names of persons were obtained during the specific interview.

disposal operations is discussed in subsection 2.3.1.2. Similar (potential) contributions from waste paper recycling centers is assessed in subsection 2.3.1.3 of the report.

2.3.1.1 Mill Residue Inventory Results

In general, the information gathered during the telephone interviews allowed two qualitative observations to be made. First, the largest sawmills now possess, or have previously held, long-term contracts with Champion International and/or Louisiana Pacific for purchase of their mill wastes. Second, these two industrial consumers have "captured" all but the smallest producers whose waste cannot cost-effectively be collected and transported to Missoula. These owners either use the wastes on-site, give them away to friends, or sell them. These general observations are discussed in greater detail in the following paragraphs.

The respective Helena and Deer Lodge-based subsidiary companies (Table 2-1) of Champion International (CI) and Louisiana Pacific (LP) send their wastes to one or the other of the Missoula operations. The other sawmill operations (Table 2-1) known to have committed at least portions of their wastes to CI and/or LP are summarized in Table 2-6. Data on company-specific waste generation quantities were not volunteered by the respective operators. However, it is the author's impression that the commitments are long-term, and that such residues should not be assumed to be accessible to the potential FGE facility. Besides the companies shown in Table 2-6, three other waste producers have allowed their respective contracts with CI to lapse. The Blackfoot Treating Plant/Lincoln Log Cabins generate collectively about 1000 units

TABLE 2-6.--SAWMILL WASTE PURCHASE AGREEMENTS PRESENTLY IN EFFECT WITH THE MAJOR INDUSTRIAL CONSUMERS LOCATED IN THE MISSOULA AREA

Sawmill Company[a]	Waste Type			
	Hogfuel	Chips	Sawdust	Comments
Hall/Alt Lumber Company	--	C.I.[b]	L.P.[b]	Delivery contracts are effective for the next 2 to 3 years.
R and R Lumber Company	C.I.	C.I.	--	C.I. has bought sawdust in the past, b is not doing so presently; owners assum 5 to 7 cunits[c] produced per day.
Pyramid Mountain Lumber Company	C.I.	C.I.	C.I.	Contract states that wastes cannot be sold to anyone besides C.I. without their expressed knowledge and permission.

Notes:

a) Full address/operator contact/phone number information for these companies is found in Table 2-1.

b) C.I. = Champion International;
L.P. = Louisiana Pacific.

c) A cunit is 100 cubic feet of material.

(375 green tons) per year of peeler shavings, and sawdust; in better economic times, it is estimated that they can produce two to three times the above amount of wastes. Company management has been informed that CI may purchase a portion of the stockpiled residues as early as this fall. Woodhurst Lumber produces approximately 1000 cubic yards (717 green tons) of sawdust per year, and would sell it to a local consumer if the opportunity arose. The approximate 1000 cords of slabs generated per year are sold for firewood. The Bouma Post Yard produces an estimated 25 tons per day of various mill wastes. Their contract with CI has expired, and has not been renegotiated to date. A Kansas firm has evaluated the post yard residue production figures and concluded that a 1.6 million gallon per year alcohol facility is feasible. Unfortunately, no formal documentation of this resource assessment or further details on the firm are available (Mr. Harold Bouma, personal communication).

The small mills whose waste have never been committed on a long-term basis to the CI and/or LP operations are presented in Table 2-7. The respective quantities of wastes should be taken as "ball park" estimates only. This is due largely to the lack of detailed "waste accounting procedures" practiced by many of the operators shown in Table 2-7. A summation of the presently uncommitted wood residue production estimates yields a value of 1414.4 green tons per year.

In regards to wood waste production from secondary manufacturing operations (Table 2-2), none of the residues generated by either the Foley Cabinet and Fixture Works or Yuhas Millwork are committed to some industrial use. Information received from Mr. Pat Foley indicates that about 156 tons of low-moisture (i.e., 4 to 8 percent-by-weight) wood waste is generated per year.

TABLE 2-7.--ESTIMATED WASTE PRODUCTION FIGURES FROM LINCOLN-AREA SAWMILLS NOT POSSESSING PURCHASE AGREEMENTS WITH THE MAJOR INDUSTRIAL CONSUMERS LOCATED IN THE MISSOULA AREA

Sawmill Company[a]	Waste Type		
	Slabs/Bark	Sawdust	Comments
Granite Timber Treating	--[b]	--[b]	Presently produce a total of 6.6 to 10.0 tpd of wastes; some of the slabs are purchased by the USFS for campground wood.
Gean Debree	--	--	Estimates a present production of about 1 ton of wastes per year.
Martin Drivdahl	~ 35 tpy	~ 8.8 tpy	Slabs sold for firewood, while sawdust sold for garden mulch, livestock bedding, etc.
Morris Lumber Company	--	--	May produce up to 1228 tons of waste per year; slabs sold for firewood.
Warren Wood Sawmill	--	~ 8.6 tpy	Sawdust used for garden mulch, while the slabs are burned or used for fencing.

Notes:

a) Full address/operator contact/phone number for these companies is found in Table 2-1.

b) No specific values are given in those cases where the owner either did not offer an estimate (or known value), or could not give sufficient information for the author to estimate one.

TABLE 2-7.--ESTIMATED WASTE PRODUCTION FIGURES FROM LINCOLN-AREA SAWMILLS NOT POSSESSING PURCHASE AGREEMENTS WITH THE MAJOR INDUSTRIAL CONSUMERS LOCATED IN THE MISSOULA AREA (Continued)

Sawmill Company[a]	Waste Type		Comments
	Slabs/Bark	Sawdust	
Jerry Montelius	--[b]	--[b]	Produces a total of ~ 95.4 tons of waste per year; C.I. has not acquired these wastes due to excessive collection/transportation costs.
Dave Sheets	--	--	Estimates a total production of $\leq$ 5 tons per year; sawdust used for livestock bedding, and slabs for firewood.
Joe Applegate	--	~ 14.3 tpy	Slabs are consumed for firewood, while no one has offered to remove the sawdust from his property.
Laurence Beck	--	--	Could not estimate the waste quantities, doubting that there was "enough to bother with". Author estimates a total of $\leq$ 5 tons per year.
Soren Beck	--	--	Refused to estimate quantities; author estimates a total value of $\leq$ 5 tons per year.

Notes:

a) Full address/operator contact/phone number for these companies is found in Table 2-1.

b) No specific values are given in those cases where the owner either did not offer an estimate (or known value), or could not give sufficient information for the author to make an estimate.

These materials have not been utilized by pulping mills as such processes apparently require "green", moist, chips, (Mr. Pat Foley, personal communic - ation). The Yuhas Millwork presently produces approximately 2 tons per month of kiln-dried sawdust (i.e., 8 to 12 percent-by-weight moisture); full-capacity operations would produce about 10 tons per month of sawdust, etc. Apparently, CI views such production levels as being "too small to deal with," (Mr. Quinton Yuhas, personal communication). "Dozens of ranchers" remove sawdust from the waste bins for use as livestock bedding material.

In conversing with various individuals listed in Table 2-1, average FOB prices paid by the Missoula-based industrial consumers were ascertained. The respective prices per kiln-dry ton are as follows: chips, $32; sawdust, $8; and hogfuel, $6.50. The equivalent prices per green ton are approximately 93.8 percent of the kiln-dry prices. This information is sufficiently accurate for general, short-term planning efforts. Given the forecast of industrial demand for wood fiber exceeding apparent supply over the next seven years, (Keegan and Lenihan, 1983), the above prices could increase considerably.

In summary, pessimistic and optimistic estimates of total annual mill wastes available for FGE production (within the defined study area) are 1725.6 and 3821.5 green tons. Both of these estimates are based on two critical assumptions: 1) that none of the Table 2-6 residues but all of the Table 2-7 residues are economically accessible to the FGE facility; and 2) that all of the residues generated by the Foley and Yuhas manufacturing processes are economically accessible to the FGE facility. The optimistic estimate assumes that one-half of the wastes produced by the Woodhurst, Blackfoot, and Bouma operations will be economically accessible to the FGE facility throughout the operating life of the FGE plant.

2.3.1.2 Municipal Wood Fiber Recovery

In 1980, a projected 36,422 tons per year of processable waste was produced within 50 miles of Lincoln (Henningson et al., 1976b). If the percentage-by-weight of these wastes that is combustible is assumed to be the same as the weight that is fermentable, then 77 percent of the total residue (i.e., 28,045 tpy) should be acceptable as FGE feedstock material (Henningson, et al., 1976a, p. 3). The quantity of FGE feedstock could rise to 38,141 per year by 1990, assuming the following two conditions hold true. First, it is assumed that the statewide solid waste generation rate of about 4.28 pounds per person-day average is applicable to the defined study area (Henningson, et al., 1976b, P. I-4). Second, it is assumed that waste generation rates will remain directly proportional to population growth projections.

Estimated delivery costs incurred for hauling waste from regional landfills located within or adjacent to the study area to the FGE facility range from $1.27 per ton to $69.11 per ton, as shown in Table 2-8. These cost estimates assume: 1) that solid waste delivery to a given landfill is paid for through routine waste collection fees or taxes; 2) that the cost for separating the fermentable waste (from the total bulk) is essentially zero (i.e., a successful public education program is in place that encourages such waste segregation at the various primary collection points); and 3) that handling costs at

TABLE 2-8.--SUMMARY OF SOLID WASTE TRANSPORT COSTS FROM LOCAL LANDFILL SITES TO THE LINCOLN-BASED FGE FACILITY (IN 1983 DOLLARS PER TON)

Landfill Location (Road Miles from FGE Site)	Haul Method	
	Roll-Off Container[a]	Transfer Trailer[b]
Deer Lodge (75)	47.55	31.65
Helena (59)	37.41	24.90
Lincoln (2)	1.27	0.84
Philipsburg (109)	69.11	46.00

Notes:

a) Assumes the use of a 40 cubic yard compacted roll-off container truck having a crew size of 1 and capacity of 10 tons; general round-trip operating costs were set at $0.317 per ton per mile.

b) Assumes the use of a 65 cubic yard transfer trailer having a crew size of 1 and haulage capacity of 18 tons; general operating costs were set at $0.211 per ton per mile.

Source:

The costs (in 1976 dollars) were taken from Table A-6 from Henningson _et al._, 1976b; they were adjusted to 1983 dollars using 1976 and projected 1983 wholesale price indices of 183 and 322, respectively.

the FGE site can be set at zero dollars, or at least be minimized by prorating the overall feedstock handling costs.

Although the above assumptions are clearly optimistic, the transfer tractor-trailer haulage costs (Table 2-8) are generally less than the $43.60 per green ton ceiling price affordable for logging residues (MultiTech, 1983); the Philipsburg haulage costs appear to be the exception to this general observation. If the total cost incurred by the above three assumptions does not exceed one-half the haulage cost from specific landfill sites to the FGE site, then "ultimate" costs per green ton of processable waste should be about $47.48. In such case, much of the processable wastes collected at the Helena and Deer Lodge landfill sites would be economically feasible sources of feedstock for FGE production. The area-wide landfill located in Helena could receive approximately 2673 tpy of fermentable waste from Boulder and Townsend.

On the other hand, the approximately 466 tpy of fermentable wastes from Philipsburg do not appear to be economically accessible from the Lincoln FGE site. The net effect of these waste-handling evaluations on the previous annual production estimates are as follows: 1) the estimated 1980 area-wide production of fermentable wastes would increase from 28,045 tpy to 30,252 tpy, while 2) the estimated 1990 production would increase from 38,141 tpy to 41,143 tpy.

2.3.1.3 Recycled Waste Paper Products Inventory

Table 2-5, Part A, presents information on the local recycling centers contacted during this phase of the inventory study. The respective managers were interviewed by phone regarding the estimated amount of waste paper handled and the use of waste paper by other industrial consumers.

Data specific to each recycling center are considered proprietary (Mr. Doug Stewart, personal communication), so only total quantities per product type will be discussed here. The monthly average for newsprint and corrugated containers is approximately 100 tons and 85 tons, respectively. The respective average prices are approximately $45 and $76 per ton; the higher quality computer printouts sell at around $200 per ton. The haul cost generally averages about $1 per load-mile if the wastes are transported via truck (Mr. Doug Stewart, personal communication).

The Pioneer Insulation Company (located in Great Falls) purchases newsprint on an intermittent basis. Fibers International, an Oregon-based "pulp broker" firm, purchases old corrugated containers, most of which are then resold to pulping mills located in southeast Asia and Japan. A Wenatchee, Washington firm consumes major portions of the corrugated containers processed by the Five Valley Recycling center in Missoula. Apparently, the Washington firm uses these materials for lining apple crates prior to shipment. In general, the demand for such paper feedstock at least equals present supply, and new consumers will face stiff competition in acquiring these materials. The $45 per ton (average) price for newsprint appears to be marginally affordable by the FGE operations; however, the approximate $1 per load-mile haul cost reduces the supply area considerably. Montana Recycling, Inc. (Missoula) would be willing to negotiate long-term feedstock supply contracts with the FGE operations if the price paid is competitive with that received from other users.

2.3.2 Livingston Study Area

The methodologies discussed in Section 2.2 were applied to inventorying the defined waste fiber categories present within approximately 50 miles of Livingston. The estimated annual production of coarse and fine wastes generated from sawmill and secondary manufacturing operations is presented in subsection 2.3.2.1. The potential recovery of processable wood fiber from municipal solid waste disposal facilities is discussed in subsection 2.3.2.2. Potential contributions from waste paper recycling centers is evaluated in subsection 2.3.2.3 of this report.

2.3.2.1 Mill Residue Inventory Results

In general, the information gleaned from the telephone interviews indicated results similar to those observed in the Lincoln area. The largest sawmill operations possess written or verbal agreements for long-term shipment of the various wastes to the Champion International (CI) operations. Furthermore, the residues not captured by CI are of uncertain supply or insufficient quantity to be cost-effectively collected and transported back to Missoula. In such cases, the owners either use the wastes on-site, give them away to friends, or sell them. These general observations are discussed in greater detail below.

The Plum Creek and Brand S Lumber Company operations have committed their mill wastes to CI. Plum Creek wastes not shipped to CI are hogged and burned on-site. The contract between CI and Brand S Lumber allows for the release of up to 35 percent of total wastes to other consumers through 1985; such quantities would total approximately 705 green tons per month. The other sawmill operations (Table 2-3) known to have committed at least portions of their wastes to CI include the Lumber Enterprises facility at Gallatin Gateway and the Willow Creek Lumber Company in Livingston. Willow Creek has a "verbal agreement" with CI for purchase of chips and intermittent purchase of bark for hogfuel. The estimated 10 tpd of sawdust is hauled to feedlot operations in the Helena area. The bark not sold for hogfuel, especially from Douglas fir trees, is purchased by a decorative bark facility in Townsend. The Willow Creek sawmill presently transports chips and a portion of its coarse wastes to the CI operations. About 25 to 30 tpd of sawdust and planer shavings are presently uncommitted to other users. However, there is some interest in pelletizing the wastes for use in wood stoves, and this should be viewed as a competitor for these materials (Mr. Bob Hansen, personal communication).

The sawmills whose wastes have never been committed to the CI operations are shown in Table 2-9. The quantities of mill wastes should be taken as reasonable approximations only. This is due largely to the lack of detailed, long-term, "waste accounting procedures" practiced by many of the operators shown in Table 2-9. A summation of the presently uncommitted wood residue production figures yields a value of about 2484 green tons per year. An additional 900 to 1200 green tons of stockpiled wastes are probably available for "one-time-only" consumption.

The mill wastes produced by the area's secondary manufacturing operations (Table 2-4) are committed largely to other uses. The wastes produced by Lumber Enterprises, Inc. during log home manufacture are sold to CI, along

TABLE 2-9.--ESTIMATED WASTE PRODUCTION FIGURES FROM LIVINGSTON-AREA SAWMILLS NOT POSSESSING PURCHASE AGREEMENTS WITH THE MAJOR INDUSTRIAL CONSUMERS LOCATED IN THE MISSOULA AREA

Sawmill Company[a]	Waste Type		
	Slabs/Bark	Sawdust	Comments
Dave Menuey	--[b]	about 37 tpy	Possess ~ 185 tons of sawdust that has accumulated over the past 4 to 5 years; he would sell it, "if they had the chance." The slabs are either given away for firewood or burned on-site.
Sarrazin Lumber Company	--[b]	about 100 to 150 tpy	The quantities of either waste could not be determined by the owner; information received indicates the stated range of estimated production. The sawdust is presently used for livestock bedding, but would be sold, "if an opportunity arose." The slabs are sawn into firewood and sold locally.
Ralph Cosgriff	--[b]	--[b]	Sawdust has been piled, but total quantity could not be estimated. The slabs and edgings are burned on-site for firewood.

Notes:

a) Full address/operator contact/phone number for these companies is found in Table 2-3.

b) No specific values are given in those cases where the owner either did not offer an estimate (or known value), or could not give sufficient information for the author to estimate one.

TABLE 2-9.--ESTIMATED WASTE PRODUCTION FIGURES FROM LIVINGSTON-AREA SAWMILLS NOT POSSESSING PURCHASE AGREEMENTS WITH THE MAJOR INDUSTRIAL CONSUMERS LOCATED IN THE MISSOULA AREA (Continued)

Sawmill Company[a]	Waste Type		
	Slabs/Bark	Sawdust	Comments
Timberline Sawmill	--[b]	about 1872 tpy	Produce approximately 28 tpd of chips and sawdust. Ranchers purchase the sawdust for livestock bedding, while the slabs are sold for firewood.
Morris Tronrud, Jr.	--[b]	--[b]	Informed by Mrs. Tronrud that they operate "a private mill, and use all the waste ourselves."
Belgrade Post Yard	--[b]	about 450tpy	Total waste production is abpit 7 tpd, whi is presently hogged and burned on-site; the owner is willing to sell wastes for FGE production.
Idaho Pole Company	--[b]	N/A	Produces about 118.5 cubic yards of shredded cedar/lodgepole pine peels per day. C.I. has not purchased the material, as the supply is intermittent and seasonal.

Notes:

a) Full address/operator contact/phone number for these companies is found in Table 2-3.

b) No specific values are given in those cases where the owner either did not offer an estimate (or known value), or could not give sufficient information for the author to estimate one.

with the sawmill wastes discussed previously. The Hoeger Wood Products firm generates one-inch diameter scraps, "given to older folks for kindling," while the sawdust is used by a neighbor for burying dead livestock. These residues will continue to be used in this way into the foreseeable future (Mrs. Virginia Hoeger, personal communication).

Average prices per kiln-dry ton of sawdust and hogfuel were calculated to be \$21.00 and \$2.81, respectively. Given the forecast of industrial demand (for wood fiber) exceeding supply over the next seven or more years, (Keegan and Lenihan, 1983; Mr. Chuck Keegan, personal communication), the above price estimates could increase considerably.

In summary, pessimistic and optimistic estimates of total annual mill residue production economically accessible for FGE production are about 2484 and 5880 green tons, respectively. The former estimate assumes that only the wastes discussed in Table 2-9 are available to the FGE operations. The latter estimate uses the Table 2-9 data and the following three assumptions. First, it is assumed that 10 percent of the "negotiable wastes" (i.e., about 35 percent of the total wastes) produced per month by the Brand S Lumber operations will be accessible to the FGE operation; if true, about 846 green tpy of feedstock can be expected from this sawmill. The second assumption is that Lumber Enterprises will sell, over the long-term, 25 percent of its sawdust to the FGE facility; if true, this would contribute about 250 green tpy of feedstock to the FGE operations. The third assumption is that 50 percent of the sawdust produced by Willow Creek Lumber Company would be purchasable by the FGE facility, for a total from all the mills of about 2300 green tpy.

2.3.2.2 Municipal Wood Fiber Recovery

In 1980, an estimated 41,320 tons of potentially processable waste was produced within the 50-mile radius study area (Henningson _et al_., 1976b). If the percentage-by-weight of combustible wastes is the same as the fermentable wastes, then 77 percent of the total residue (i.e., 31,816 tpy) should be acceptable as either boiler or alcohol FGE feedstock material (Henningson, _et al_., 1976a, p. 3). The quantity of FGE feedstock could rise to 43,270 tpy by 1990, assuming the following two conditions hold true. First, it is assumed that the state-wide solid waste generation rate of about 4.28 pounds per person-day average is applicable to the defined study area. Second, it is assumed that waste generation rates will remain directly proportional to population growth projections.

Estimated delivery costs incurred for hauling waste from regional landfills located within or adjacent to the study area to the FGE facility will range from $1.27 per ton to $46.28 per ton, as shown in Table 2-10. These cost estimates assume: 1) that solid waste delivery to a given landfill is paid for through routine waste collection fees or taxes; 2) that the costs for separating the fermentable wastes (from the total bulk) is essentially zero (i.e., a successful public education program is in place that encourages such waste segregation at the various primary collection points); and 3) that handling costs at the FGE site can be set at zero dollars, or at least be minimized by prorating the overall feedstock handling costs.

Although the above assumptions are clearly optimistic, the transfer tractor-trailer haul costs (Table 2-10) are less than the $43.60 per green ton ceiling

TABLE 2-10--SUMMARY OF SOLID WASTE TRANSPORT COSTS FROM LOCAL LANDFILL SITES TO THE LIVINGSTON-BASED FGE FACILITY (IN 1983 DOLLARS PER TON)

Landfill Location (Road Miles from FGE Site)	Haul Method	
	Roll-Off Container[a]	Transfer Trailer[b]
Bozeman (27)	17.12	11.39
Livingston (2)	1.27	0.84
White Sulfur Springs (73)	46.28	30.81

Notes:

a) Assumes the use of a 40 cubic yard compacted roll-off container truck having a crew size of 1 and haulage capacity of 10 tons; general round-trip operating costs were set at $0.317 per ton per mile.

b) Assumes the use of a 65 cubic yard transfer trailer having a crew size of 1 and haulage capacity of 18 tons; general operating costs were set at $0.211 per ton per mile.

Source:

The costs (in 1976 dollars) were taken from Table A-6 from Henningson et al., 1976b; they were adjusted to 1983 dollars using 1976 and estimated 1983 wholesale price indices of 183 and 322, respectively.

price affordable for logging residues (MultiTech, 1983). If the total cost incurred by the above three assumptions does not exceed one-half the haul cost from specific landfill sites to the FGE site, then "ultimate" costs per green ton of processable wastes should be about $46.22. In such case, the processable wastes collected at the Bozeman, Livingston, and White Sulfur Springs landfill sites would be economically feasible sources of feedstock for FGE production.

2.3.2.3 Recycled Waste Paper Products Inventory

Table 2-5, Part B, presents information on the local recycling centers contacted during this phase of the inventory study. The managers were interviewed by telephone regarding the estimated amount of waste paper handled and the uses of paper waste by other industrial consumers.

The data specific to each recycling center are considered proprietary (Mr. Doug Stewart, personal communication), so only total quantities per product type will be discussed here. The present monthly average for newsprint and corrugated container feedstock is approximately 95 tons and 100 tons, respectively. The respective average prices (excluding transport) are approximately $65 and $80 per ton; the higher quality computer printouts are sold at around $160 per ton. The haul cost generally averages $1-plus per load-mile if transported by truck (Mr. Doug Stuart, personal communication).

In general, recycled paper is shipped to the west coast, or beyond to overseas locations, for pulping purposes. Some of the newsprint is sold, on an intermittent basis, to the Pioneer Insulation Company's operations in Great Falls.

Furthermore, local grocery establishments sell their corrugated containers directly to west coast "pulp brokers" when the market conditions are favorable. Overall, the short-term prices fluctuate markedly, due to international market activities, for the various paper products. In response to such fluctuations, the supply of a particular paper waste type also varies considerably.

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PERSONAL CONTACTS

The names of those persons interviewed by phone who operate either sawmills, mill works, or recycling centers are listed by study area in Tables 2-1 through 2-5, and subsequently will not be repeated here. The personal contacts given below are for those individuals interviewed who are not cited in any of the above tables.

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Betts, Dick, March 21, 1983. USDI, BLM, Garnet Resource Area; Supervisory Forester, Missoula. Phone conversation.

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Gossard, Boyd, March 21, 1983. USDA, Lolo National Forest; Timber Management Administrator for the Seeley Lake Ranger District, Seeley Lake, Montana. Phone conversation.

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